Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29491

294 (2023) 100–110
May

Nano-banana peel bio-coagulant in applications for the treatment of turbid and river water

Mohandhas Dharsana, Arul Jose Prakash*

Department of Civil Engineering, Noorul Islam Centre for Higher Education, Thuckalay, Kanyakumari, Tamilnadu, India, emails: joseprakash1430@gmail.com (A.J. Prakash), dharsanamohandhas@gmail.com (M. Dharsana)

Received 26 September 2022; Accepted 21 March 2023

ABSTRACT

As the world population increased the consumption of water and water treatment becomes critical. So, this research investigates the use of banana peel waste as a natural coagulant, eco-friendly modification of coagulation, synthetic water turbidity reduction, and river water purification. In this case, the typical particle size of the banana peel powder was 978 ± 37 nm, and the modified powder was 571 ± 41 nm. The effectiveness of the coagulation was examined at various pH values, dosages, sedimentation periods, and NaCl concentrations. Up to 90% turbidity removal with 0.4 g/L of modified banana peel was found. While the coagulation performance was somewhat improved at concentrations of less than 0.4 g/L of NaCl, the activity was reduced, even in the modified powder, at higher concentrations. Banana peel powder significantly reduced watercolor, total dissolved and suspended solids, and chemical and biochemical oxygen demand in river water but only reduced turbidity by 75% and 83%, respectively, for non-modified and modified powders. The coagulation process was investigated and confirmed using scanning electron microscopy and Fourier-transform infrared spectroscopy. Banana peel powder modified in this environmentally friendly way has a lot of potential as a cheap and accessible bio-coagulant and can likely help to decrease wastage.

Keywords: Coagulant; Modification; Nano-banana peel powder; Turbidity; Water treatment

1. Introduction

With the booming population, water consumption, and availability are dramatically increased globally [1,2]. A large amount of particles and dissolved contaminants makes sources of water unsuitable for daily needs, particularly in tropical nations [3]. The contaminations, which contain organic and inorganic minerals and chemicals, affect the physical, chemical, and biological properties of water [4,5]. Therefore, surface water goes through many stages of treatment and purification depending on the quality of the water and before consumption [6,7]. The use of coagulants to remove the impurities like color and turbidity from water which is finally settled at the bottom of the vessel and removed is one of the water treatment methods that rely on coagulation [8].

Several chemicals (non-plant) based coagulants such as iron oxide salts, in addition to various polymer nanocomposites, have been evidenced in water treatment applications [9]. The most popular metal saltwater treatment coagulants are those based on aluminum (sulfates of aluminum and chloride) and ferric (sulfate of ferrous and ferric chloride) [10]. Ferric chloride and aluminum sulfates are the most common coagulants used for the treatment of wastewater with excellent performance. On another hand, chemical coagulants are dramatically changing the pH level and reduced it to a level close to acid. Moreover, the consumption of hose water affects human health and causes presenile dementia

* Corresponding author.

and Alzheimer's disease [11]. Results proved that polyaluminum chloride is an effective coagulant for the removal of dissolved humic acid from water [12]. Both polyaluminum chloride (PACl) and polyaluminum ferric chloride (PAFCl) have an appropriate capability to remove humic acid from surface water; however, PAFCl has shown superior performance in the treatment of aluminum residuals [13]. The metal salt coagulant agents have the main drawback while treating the water that produces a high amount of sludge and it is costly [14]. Consequently, the organic base coagulants are the appropriate and better substitutions for any of these chemicals.

Water treatment applications have utilized a variety of organic coagulants, such as *Moringa oleifera* [15], *Dolichos lablab* [16], and *Cicer arietinum* [17]. These substances are containing multiple potent proteins that are in charge of peels, while the process of coagulation causes suspended particles from water chemically destabilizes into larger agglomerates [18]. The main advantages of natural coagulants have been studied, natural coagulants are safe for human health [14] and the sludge generated in treating water is often biodegradable, free from toxins, locally available, and economical [19]. Applications for water purification have used extensive synthetic materials, such as cationic polymers [20], nanoparticles of manganese ferrite [21], and nanoparticles of titania [22]. However, some of the natural coagulants are more expensive and not vastly available which may limit their use [23]. *Moringa oleifera* seeds as a natural coagulant provide better efficiency of turbidity but also noticeable color removal from sewage [24]. Papaya seed for the same objective and has a direct link between the effectiveness of removal and coagulant dosage [25]. The seeds from plants may not be readily available as large and might be used for other plant-based things instead. This investigation used a natural coagulant by-product from banana peel.

The banana tree has been claimed to produce from three to twenty fruits in a cluster only once a life span, and once the fruit has been consumed, various parts of the banana tree are not utilized, such as banana peels as well as stems, which are thus considered as waste [26]. These organic components having low molecular weight, contains significant amounts of cellulose, lignin, pectin substances, pigments, chlorophyll, and other valuable organic substance [27]. Every year, millions of tons of banana peels are thrown after consumption. The second most extensively grown fruit in south India is the banana, which may be eaten either ripe or unripe. Unripe bananas are used to make chips, whereas ripe bananas are utilized to prepare fried bananas in the area. Huge volumes of bananas are used by chip and juice manufacturers each year, and they produce a lot of leftover banana peel. Approximately 30%–40% of the total weight of banana is covered by peels, which are typically disposed of in open space and leads to environmental issues. Recent studies revealed that banana peels are mostly composed of several biopolymers such as pectin, cellulose, lignin, and hemicellulose, as well as hydroxyl and carboxyl functional groups chemical compounds [28]. These compounds of banana peels contribute to completing, coordinating, chelating, hydrogen bonding, and/or other processes. As a result, these functional group components in banana peels are the most suitable natural coagulant for applications involving water treatment. Banana peels have already been subjected to numerous attempts to improve coagulation performance, either with some other flocculants or by chemical alterations to the fruit peel [29]. Chemical treatment could exacerbate existing problems by causing chemical leaching in treated water. Therefore, this study improved the efficiency of the banana peel as a coagulant by using an easy and inexpensive preparation approach. This method involves microwave radiation treatment followed by grinding operations numerous times to alter the particle surface and reduce the particle size. Their findings supported and suggest that no need for any chemical reaction process to enhance the coagulation effectiveness of the natural coagulant. Banana peels with and without modifications were tested at various doses, pH levels, sedimentation rates, and NaCl concentrations. By contrasting the impact of banana peel particle size and banana peel solution in a turbid water treatment, the inside function of banana peel powder coagulation was also examined.

2. Material and method

2.1. Materials

The dry and fully matured red banana fruit (*Musa acuminata*) was collected from a local market of Kanyakumari (South India) and was categorized by a horticulturist to ensure the species. White kaolin clay where Kaolin Techniques Private Limited, Gujarat, India, and local market available research grade NaCl solution was used.

2.2. Nano-banana peel powder preparation

The fresh banana fruits were cleaned, peeled, and sliced into small pieces, and were air-dried for 20 d at room temperature. To create the common banana peel powder, the peels were ground into a very fine powder using a ball mill after complete drying. Using a green method that involved microwave treatment, modified banana peel powder was produced. The powder was first made using the previously indicated procedures and the powder was treated numerous times by using a microwave oven at the energy of 700 W for 0.25 min, followed by chilling and grinding to modify the particle size and the surface morphology of the peel powder.

2.3. Nano-banana peel solution preparation

The solution was made by measuring banana peel powders 10 g each and adding them independently to a liter of distilled water. To make sure that every protein and active substance was completely dissolved, the suspension was agitated for 1 h with a magnetic stirrer. After that, it was allowed to settle down for 30 min. Finally, the remained filtrate was collected, and its concentrations ranging from 1% to 10% by weight were made.

2.4. Nano-banana peel powder's characteristics

The morphological properties of nano-banana peel powder (modified and non-modified) were studied by using a scanning electron microscope (SEM) of a model (JEOL-JSM-IT 200 with EDS). Laser diffraction analyzer of (LA-960, India) where used to examine the particle size distribution. Each powder was suspended in 0.01% consistency and dispersed using ultrasonic for 15 min at 100% power throughout a size range of 1–100 mm. Using Fourier-transform infrared spectroscopy (FT-IR) the banana peel powders the functional groups were analyzed.

2.5. Standardization and preparation of turbid water

For all coagulation studies, synthetic turbid water was used to provide a constant turbidity value. To create the stock solution, kaolin clay particles of 10 g were first added to deionized water of 1 L [30]. The solution was diluted with deionized water to achieve a turbidity standard of 110 NTU. The river water was obtained from Valli Aaru (One of the most important river in Kanyakumari District) as per the same process [31] and the characterization test was done for the samples.

2.6. Test for coagulation

The jar test was used to observe coagulation in action. The coagulants were put into 500 mL jars with water samples. Time and stirring speed were held constant at 200 rpm for 2 min, followed by 10 min of gradual mixing at 20 rpm and 30 min of settling [4]. Several kinds, dosages, pH, and NaCl concentrations were utilized. For all the concentration of the banana peel solution was utilized in a constant volume of 50 mL. The average of three times experiment values was recorded.

2.7. River water characterization

The collected water sample's temperature was measured by using a digital thermometer and it was held for 1 min in each sample, the average temperature was 30°C. Using various colored backdrops, the watercolor was seen with the bare eye. The collected water sample exhibits the color Faith brown. The automatic waterproof pH meter (Labpro pH Meter) where used to measure the pH value. The pH value of the collected sample was 6.2. The turbidity of the water sample was found 6.7. EU tech total dissolved solids (TDS) meter where used to measure the total dissolved and suspended solids. By using A DR2800 spectrophotometer and dissolved oxygen meter chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were measured and recorded at 35.2, 31.4, and 86.2, respectively.

3. Results

3.1. Properties of nano-banana peel powder

The modified and non-modified banana peel powders scanning microscopic images are shown in Fig. 1. The powder of non-modified particles has appeared like smoother surfaces without fractions (Fig. 1a). The modified powder, on the other hand, had rough and sticky surfaces and appeared to be more homogeneous. The banana peel powder was subjected to numerous microwave treatments, resulting in mild heating that caused fractions in the particles, as shown in Fig. 1b by the arrows, and also helps to enhance the particle size reduction. According to Eng and Loo's

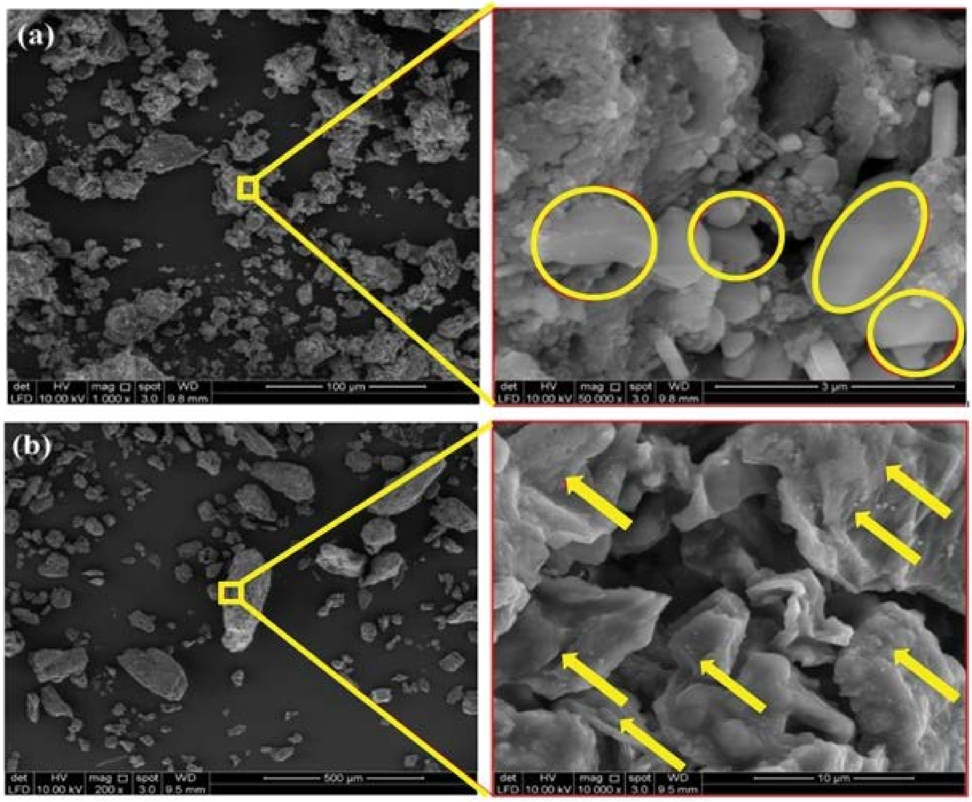

Fig. 1. Morphology of modified and non-modified banana peel powder (a) non-modified and (b) modified.

findings, traditional methods of heating and filtration of the banana peel bio-flocculent proved to be inferior [32].

According to Fig. 2a, modified banana peel powder had a particle size of 543 ± 28 nm, and non-modified banana peel powder had a particle size of 978 ± 37 nm. The FT-IR spectra of modified and non-modified powders (Fig. 2c) show a large number of functional groups, with an extensive peak of 3,421.57 cm^{-1} ascribed to the group's hydroxyl components. Including CH, CH_2, and CH_3 groups, CH stretching caused the more strong peak at 2,923.06 cm^{-1} [33]. Two further noteworthy peaks, 1,637.64 and 1,054.39 cm^{-1} are exhibiting the bonds of C=O with rings of aromatic and stretch bonds of C–O, respectively [34]. Moreover, the microwave treatment significantly enhanced surface morphology as well as the particle size of banana peel powder, but the FT-IR spectra exhibit there is no significant difference between both modified and non-modified banana peel powder particle function groups.

3.2. Coagulation test

3.2.1. Effect of dose on coagulation

The impact of varying amounts of both types of banana peel powder on the effectiveness of coagulation is shown in Fig. 3. It can be seen that on both materials, the effect was enhanced steadily while increasing the concentration. The greater removal efficiency was found in the range of 0.6 g/L for non-modified powder and 0.4 g/L for modified powder. Increased doses resulted in a decreased efficiency of removal, which could be the effect of modest polysaccharides and other different substances of the banana peel powder, which resulted in a slightly decreasing removal efficiency. But these study results proved better efficiency rather than previous studies [29]. It stated that the ideal dose limit of banana peel was around 5 g/L using a decreased turbidity of just 44 NTU. Banana peels include a variety of bio-flocculants [35]. The modified powder's reduced size and sticky edges helped release these materials, bringing them into touch with murky water. Therefore, a smaller dose around (0.4 g/L) of modified nano powder remained sufficient to remove 90% of water turbidity.

3.2.2. Effect of pH on coagulation

In neutrality circumstances with a pH value varying from 6 to 8, improved coagulation performance was exposed. Even though the modified bananas peel powder has higher activity but coagulation shows it affected both in a similar

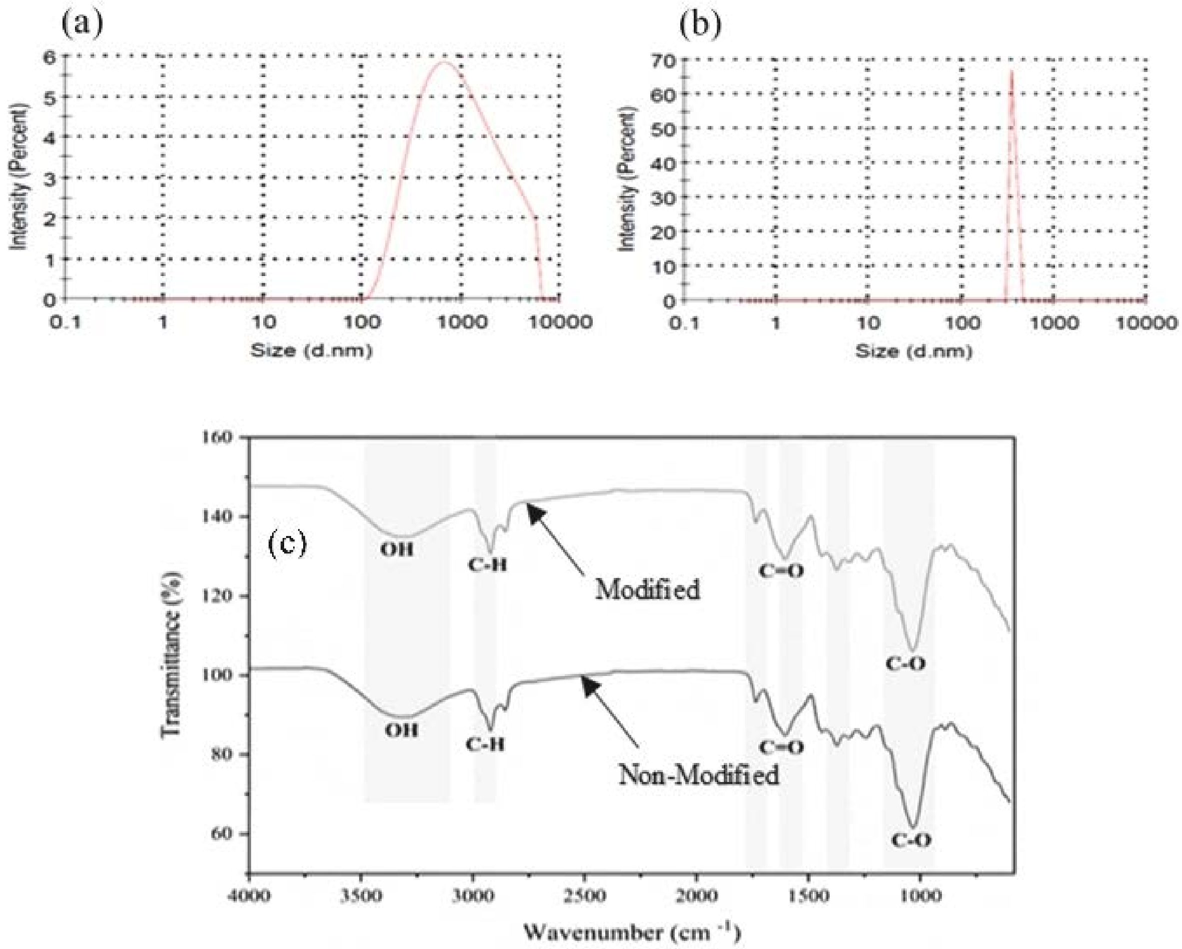

Fig. 2. Particle size analysis and FT-IR spectra of non-modified and modified banana peel powder (a) non-modified nano-banana peel powder, (b) modified nano-banana peel powder and (c) FT-IR spectra.

way shown in Fig. 4. Quite apart from the modified banana peel powder's higher activity, both responded similarly. The turbidity removal efficiency was reduced while using the optimal doses of both modified as well as non-modified banana peel powder at the pH value is 2 it was around 57% and 55% for the modified and non-modified banana peel powder, respectively. However, for modified and non-modified banana peel powder, the turbidity reduction was decreased by 78% and 62%, respectively, at an alkaline pH (pH = 11). Similar results were found in a prior study, which found that banana peels removed turbidity most effectively in normal, somewhat alkaline pH environments [36]. The coagulant cationic of treated particles of banana peel was equivalent to the number of clay particles (anionic suspension) at slightly alkaline pH, which caused to all become unstable due to the coagulation process. The study of Chong and Kiew [37] removed turbidity in both alkaline (93.4%) and acidic (81.4%) circumstances. They also showed that coagulation efficacy significantly decreased as solution pH climbed (from 4–8), but increased dramatically to pH 8 and above. This can be defined by the material intricate structure, which may also include amphoteric ions. According to findings from a prior study, the removal efficiency of banana peels contains coagulants as well as flocculants, which means the simultaneous activity of dual mechanisms [38].

3.2.3. Sedimentation time on the coagulation

The performance of the coagulation appeared to be unaffected by sedimentation time. Both samples had comparable outcomes after 30 min of sedimentation as shown in Fig. 5. On massive flocs immediately sediment after 10 min, the turbidity removal of modified and non-modified banana peel powder where scored 76%, and 64%, respectively. The powder takes some time to sediment. Previous studies also obtained similar results [39]. The studies reported that after 100 min of sedimentation, the coagulant's removal effectiveness remained steady. In this study, the optimum turbidity

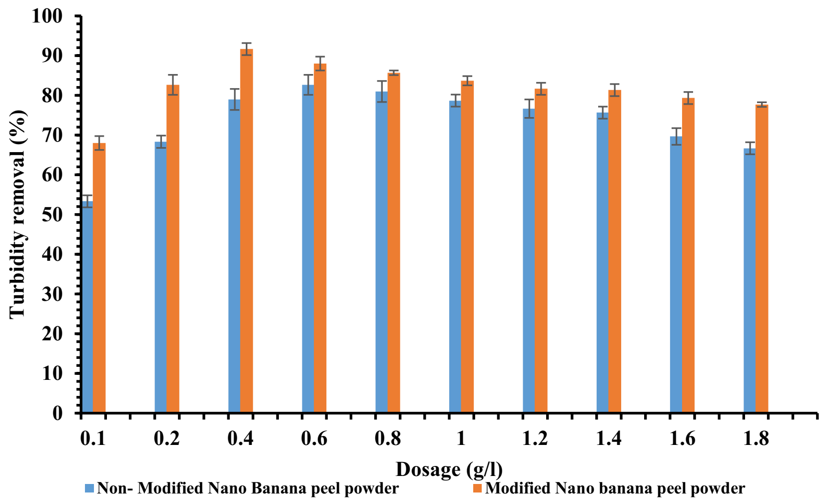

Fig. 3. Performance of the modified and unmodified nano-banana peel powder in terms of coagulation at different levels of dosages.

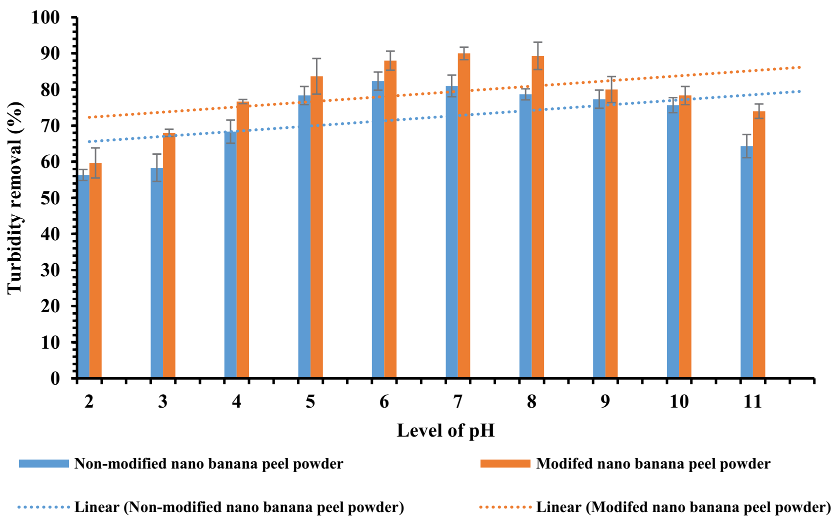

Fig. 4. Performance of the modified and unmodified nano-banana peel powder in terms of coagulation at various pH levels.

removal was achieved after only 30 min of sedimentation of all the flocs. Another study stated that the turbidity removal with the same sedimentation time while using *Moringa oleifera* aqueous extract as a coagulant. [40]. Although the sizes of the particles in this investigation varied significantly, the modified particles were still able to combine into big flocs and silt in a period comparable to that of the large particles of non-modified banana peel powder.

3.2.4. NaCl quantity on the coagulation

The result of varying dosages of NaCl upon this coagulation process of modified and non-modified banana peel powders are illustrated in Fig. 6. It exhibits the addition of a small amount of NaCl (>0.4 g/dm^3) improvement in coagulation by around 2%, meanwhile, the high quantity enhanced the drop in coagulation. The use of NaCl enhanced the solubility of banana peel powder proteins, it promotes the association of the protein breaking the other hand it enhances the protein solubility [41]. NaCl exhibits the same nature for both types of banana peel powder; it may be due to the exchange of iron particles between Na^+ irons and clay particles. It shows there is no relation between the protein content of banana peel and coagulation efficiency. This iron exchange leads to enhancing the surface charge negativity and increasing the performance of coagulation. The alteration in coagulant charges happens while adding a high amount of NaCl and it leads to control of the performance of coagulation. The previous research recorded the increasing amount of NaCl reduced the coagulation and enhanced the turbidity [42]. Although the addition of NaCl in drinking water changes the taste, it is not suitable for drinking.

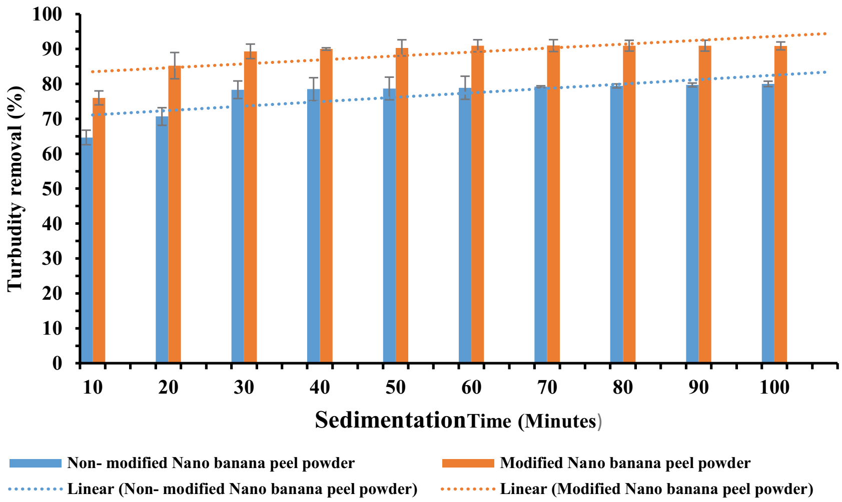

Fig. 5. Performance of the modified and unmodified nano-banana peel powder in terms of coagulation at various sedimentation times.

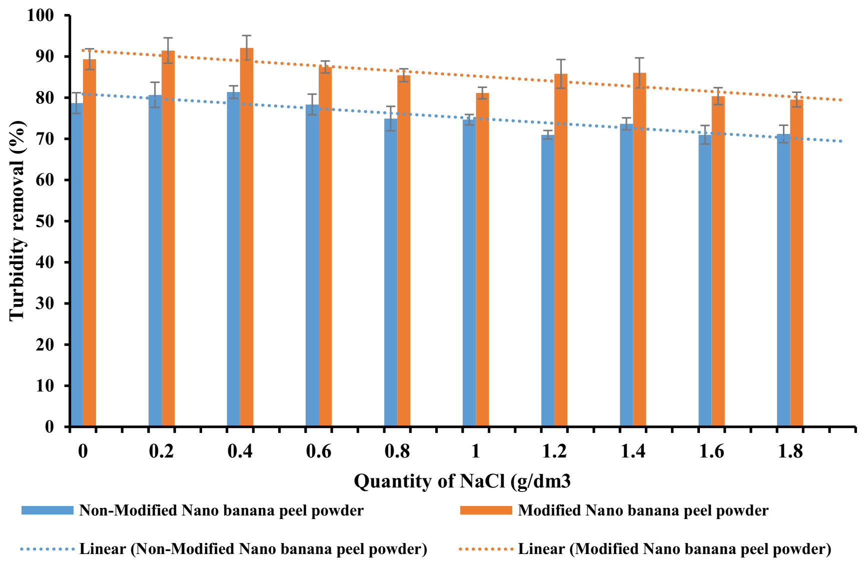

Fig. 6. Performance of the modified and non-modified nano-banana peel powder in terms of coagulation at various dosages of NaCl.

3.2.5. Powder solution on the coagulation

The low coagulation efficiency was found while using banana peel solution as a coagulant compared to banana peel powder coagulant as shown in Fig. 7. The modified banana peel solution had a good effect rather than the non-modified banana peel solution however, the impact of coagulation was constantly incensing while increasing their dosages. In low dosage limit (1% by wt.) the removal efficiency of turbidity content was almost parallel 34% and 33% were shown for modified and non-modified banana peel solutions respectively. However, the highest dosage limit is 10% by wt., and the turbidity removal efficiency was improved by 80% and 71%. The extraction of active components of banana peel powders where enhanced while doing microwave treatment [43]. The SEM images indicate the surface portion particles were fully hydrated and released the active chemicals. After microwave treatment, the banana peel surface turned rough and porous, confirming the effectiveness of the active chemicals' release [44]. The microwave treatment helped the phenolic compound extraction from banana peels [45]. The banana peel powder is stronger than the banana peel solution in coagulation [35].

3.2.6. Effect on river water-modified banana peel powder

Both modified and non-modified banana peel powders were used in river water treatment under optimal circumstances and their impacts were examined. Table 1 shows the physical and chemical characteristics of the river water before and after the treatment. It noted that the turbidity was reduced rather than syntactic turbid water while using non-modified and modified banana peel powder as a coagulant, which was reduced by 75% and 83%, respectively. Banana powders poor ability to coagulate may be the initial turbidity level of 36% and/or other chemicals or microorganisms of river water [28]. Banana peel powders contain various groups of chemicals like phosphate, hydroxyl groups, and carboxylic acid which may act as active hubs for watercolor, total suspended solids, COD, and TDS removal [46]. Banana peel powders increased adsorption capacity while doing microwave treatment it enhances the river water pollution after the modification. The adsorption ability of river water contaminants was significantly increased by modified banana peel powder. This improvement may be due to the microwave-treated particles having superior ion exchangeability and high porosity rather than non-treated particles. [47].

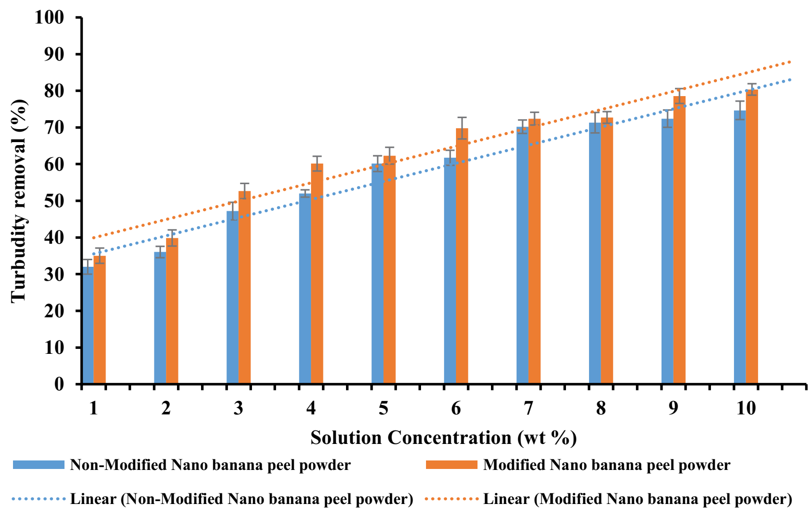

Fig. 7. Performance of the modified and unmodified nano-banana peel extract in terms of coagulation.

Table 1
Result of modified and non-modified nano-banana peel powder in river water treatment

Parameters	Before treatment	After treatment	
	Result	Non-modified nano-banana peel powder	Modified nano-banana peel powder
Temperature (°C)	30	30	30
pH	6.2	6.90	6.97
Turbidity (NTU)	6.74	8.3 (75%)	5.76 (83%)
Color	Faint brown	No-color	No-color
Total suspended solids (mg/L)	35.2	11.7	9.2
Total dissolved solids (mg/L)	43.6	8.2	5.6
Biochemical oxygen demand (mg/L)	31.4	26.1	23.2
Chemical oxygen demand (mg/L)	86.2	60.8	59.2

4. Discussion

In other investigations, the coagulation process was treated using microwaves and ultrasonic waves without considering how these treatments affected the particles themselves [48]. The brittleness of the fibers after microwave treatments may enhance the considerable reduction in particle size. Microwaves are capable of creating surface fractions on smooth surfaces, resulting in their breaking and disinterest, despite the slight heating in each treatment, which accounts for the negligible decrease in particle sizes [43]. Banana peel bio-flocculants were purified and employed; 45.16% of optimal turbidity reduction was recorded [32]. Based on this study, it can conclude that the modified banana peel powder and solutions performed well when compared to non-modified banana peel powder and respective solutions. Microwave radiation exposure causes the powder's particles to become more fractionated, which improves the powder's ability to adsorb substances and collect turbidity. In addition to explaining the decrease in turbidity, the SEM image proved the presence of pores and leads to sorption. The better removal of river contaminants supports the sorption action of the modified banana peel powder, which demonstrated the both actions of coagulation as well as sorption. The results support the findings of numerous studies on the powdered banana peel sorption mechanism [48,50,51]. The two primary known coagulation and flocculation mechanisms for the majority of naturally occurring plant coagulants are charge neutralization and bridge building [52]. The comparison of banana peel materials' coagulation performance under constant conditions, is shown in Table 1. The deposits of banana peels were thought to be unique because, at very low concentrations, there were no appreciable differences between the changed and non-modified deposit, and because it had a lower removal capacity of 38% than the modified banana peel powder, which was around 92% at the same circumstances. The majority of earlier literature described rather than raw peel powder, which raised the processing time as well as expenses processing, even though the dose of banana peel was substantially larger than that of all the studies. Table 2 compares our findings to those of other natural coagulants under various circumstances. The table illustrates the results of experiments with several natural coagulants conducted under various circumstances. But apricot seed extract and powder were employed to remove the turbidity, the efficiency varied between the range of 54% and 96%, respectively [52,53]. Under natural conditions, our study proved 92% turbidity reduction while employing modified banana peel as a coagulant.

The non-modified banana peel powder, modified banana peel powder, their respective solutions, and their coagulation performance are shown in Fig. 8 (filtrate). The main goal of utilizing a coagulant is to produce water with low turbidity, clearer in addition to eliminating very small suspected particles. The negatively charged particles attract the positively charged coagulants they are neutralized in the water. Positively charged proteins and polysaccharides found in banana peel interact with oppositely charged suspended particles to neutralize and precipitate them, meanwhile the microwave treatment modifies the banana peel particles and forms a bridge between the effectiveness of removal and particle size.

Even though ordinary particle banana peels also have positive charges, their larger size limits their ability to bridge gaps [58]. This banana peel's strong ability to absorb metal particles is a different way that banana peels can purify water. The modified powder's reduced particle size contributed to a decrease in the repelling forces between the clay particles, which increased the creation of micro flocs and improved coagulation properties. Usually, rapid mixing is employed to increase the generation of micro flocs and to cause the coagulant particle and suspended particles to collide [59]. However, because the two powders were constantly mixed in our study, the modified banana peel powder created extra microflocs more quickly than the non-modified ones. This establishment of bridge linkages subsequently encouraged the necessary effect (caused by the surface roughness) among the two powders. The small size of banana peels and suspended particles are formed in considerably larger flocs as a result of this process, which is followed by flocculation. The large size of particles may sediment without forming a large number of flocs when using non-modified banana peel powder, resulting in low performance in coagulation. The raw sample watercolor was a mild brown tint which may be because of dissolved suspended particles as well as turbidity. Following the application of both powders,

Table 2
Coagulation performances of the modified banana peel powder with different literature

Bio-coagulant	Optimal experimental conditions			Turbidity removal (%)	References
	Dose (g/L)	pH	Type of wastewater		
Moringa seed powder	0.15	6–8	Paper mill effluent	96	[56]
White popinac	0.05	7	Synthetic turbid river water	76	[54]
Banana peel extract	0.1	1	Synthetic domestic wastewater	88	[37]
Iraqi date seed extract	0.06	7	Synthetic turbid water	90	[58]
Apricot seed extract	0.03	7	Raw surface water	54	[59]
Banana peel powder	0.4	7	Kaolin synthetic wastewater	59	[61]
Jack fruit peel extract	0.1	2	Sewage synthetic wastewater	70	[60]
Non-modified banana peel powder	0.6	6–8	Kaolin synthetic wastewater	81	This experiment
Modified banana peel powder	0.4	6–8	Kaolin synthetic wastewater	92	This experiment

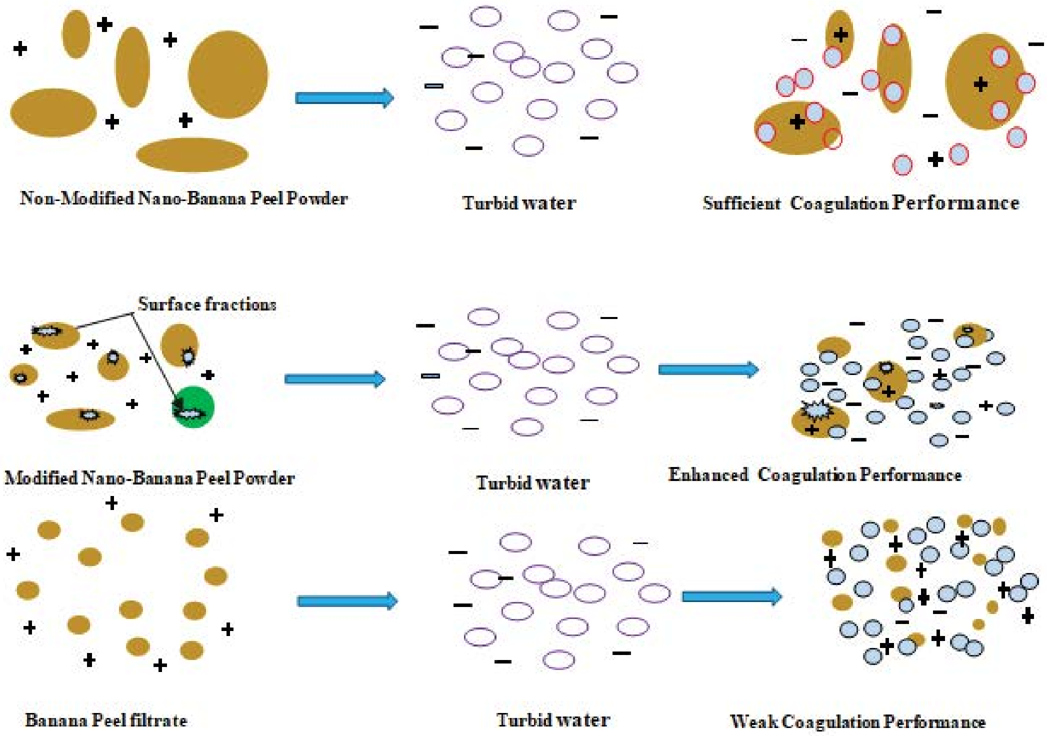

Fig. 8. Schematic diagram of non-modified and modified nano-banana peel powder, and banana peel coagulation performance.

it was found that the modified powder performed better in terms of lowering all of the parameters. The raw sample water had a chemical oxygen demand of 87.2 ± 4.2 mg/L, meanwhile modified powder made a small reduction which was around 60.2 ± 2.9 mg/L. The river water contains various types of mineral and chemical compounds but the banana peel powder action was control the flocs and bridge linkage formation. It should be noted that the surrounding particles can be coagulated by chemicals, the COD demand was limited due to this action. The same trend was found in the case of biological oxygen demand also, the modified and non-modified banana peel powders somewhat reduced from 31.6 ± 2.2 mg/L to 26.1 ± 1.7 and 24.3 ± 1.2 mg/L, respectively. Previous researchers also reported a similar kind of slight reduction in BOD [58]. Based on this experiment results the modified banana peel powder has significant effectiveness in water treatment applications as well as pollutant adsorption [58,61].

5. Conclusion

The use of plant waste has always been an excellent objective of various researchers to ensure the use of sustainable natural materials and minimize different syntactic substances. This experiment confirms the effective efficiency of waste banana peel in the application of the water treatment process. Based on all the experiments of this research the following findings are made.

- Microwave-modified nano-banana peel powder coagulates better than non-modified. Chemical and to confirm sustainable use of natural assets and minimize synthetic or chemical compounds.
- In the non-modified banana peel filtrate, the dose was weaker at the exact dosage and stronger as the dose was increased. During microwave treatment, banana peel particles become fractured and rough. As a result, particle size reduction and coagulation are enhanced.
- In addition to reducing the amount of dissolved and suspended solids in river water, as well as reducing the amount of chemical and biochemical oxygen needed, modified banana peel powder was also shown to be an excellent alternative to synthetic, chemical, or even expensive natural coagulants by reducing turbidity, color, and total dissolved and suspended solids.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Funding statement

Not applicable.

Conflict of interest

The authors don't have any conflict.

References

[1] S.Y. Choy, K.M.N. Prasad, T.Y. Wu, R.N. Ramanan, A review on common vegetables and legumes as promising plant-based natural coagulants in water clarification, Int. J. Environ. Sci. Technol., 12 (2015) 367–390.

[2] N.M. Mahmoodi, B. Hayati, M. Arami, Textile dye removal from single and ternary systems using date stones: kinetic, isotherm, and thermodynamic studies, J. Chem. Eng. Data, 55 (2010) 4638–4649.
[3] M. Rafatullah, S.Z. Abbas, A. Ahmad, D. Lokhat, A Review of Agricultural Solid Waste Materials as Potential Adsorbents for Copper Ions from Water and Wastewater, In: Air, Gas, and Water Pollution Control Using Industrial and Agricultural Solid Wastes Adsorbents, 1st ed., CRC Press, 2017, pp. 197–222.
[4] B.I. Gandiwa, L.B. Moyo, S. Ncube, T.A. Mamvura, L.L. Mguni, N. Hlabangana, Optimization of using a blend of plant-based natural and synthetic coagulants for water treatment: (*Moringa oleifera-Cactus opuntia*-alum blend), S. Afr. J. Chem. Eng., 34 (2020) 158–164.
[5] N.M. Mahmoodi, Synthesis of core–shell magnetic adsorbent nanoparticle and selectivity analysis for binary system dye removal, J. Ind. Eng. Chem., 20 (2014) 2050–2058.
[6] M. Mariana, H.P.S. Abdul Khalil, E.M. Mistar, E.B. Yahya, T. Alfatah, M. Danish, M. Amayreh, Recent advances in activated carbon modification techniques for enhanced heavy metal adsorption, J. Water Process Eng., 43 (2021) 102221, doi: 10.1016/j.jwpe.2021.102221.
[7] M. Oveisi, N.M. Mahmoodi, M.A. Asli, Facile and green synthesis of metal-organic framework/inorganic nanofiber using electrospinning for recyclable visible-light photocatalysis, J. Cleaner Prod., 222 (2019) 669–684.
[8] N.M. Mahmoodi, Dendrimer functionalized nano architecture: synthesis and binary system dye removal, J. Taiwan Inst. Chem. Eng., 45 (2014) 2008–2020.
[9] A. Nath, A. Mishra, P.P. Pande, A review natural polymeric coagulants in wastewater treatment, Mater. Today Proc., 46 (2021) 6113–6117.
[10] A. Bahadori, M. Clark, B. Boyd, Essentials of Water Systems Design in the Oil, Gas, and Chemical Processing Industries, Springer, New York, NY, 2013.
[11] K. Gurumath, S. Suresh, *Cicer arietinum* is used as natural coagulant for water treatment, Int. Res. J. Eng. Technol. (IRJET), 6 (2019) 2930–2931.
[12] R. Sudoh, M.S. Islam, K. Sazawa, T. Okazaki, N. Hata, S. Taguchi, H. Kuramitz, Removal of dissolved humic acid from water by coagulation method using polyaluminum chloride (PAC) with calcium carbonate as neutralizer and coagulant aid, J. Environ. Chem. Eng., 3 (2015) 770–774.
[13] M. Faraji, A. Ebrahimi, H. Nourmoradi, A. Nikoonahad, A. Abdolahnejad, R. Ghanbari, A. Mohammadi, Optimizing the removal of humic acid with polyaluminum chloride and polyaluminum ferric chloride as green coagulants using response surface methodology, Desal. Water Treat., 139 (2019) 297–304.
[14] H. Kristianto, The potency of Indonesia native plants as natural coagulant: a mini review, Water Conserv. Sci. Eng., 2 (2017) 51–60.
[15] A.S. Taiwo, K. Adenike, O. Aderonke, Efficacy of a natural coagulant protein from *Moringa oleifera* (Lam) seeds in treatment of Opa reservoir water, Ile-Ife, Nigeria, Heliyon, 6 (2020) e03335, doi: 10.1016/j.heliyon.2020.e03335.
[16] B.L.C. Lek, A.P. Peter, K.H.Q. Chong, P. Ragu, V. Sethu, A. Selvarajoo, S.K. Arumugasamy, Treatment of palm oil mill effluent (POME) using chickpea (*Cicer arietinum*) as a natural coagulant and flocculant: evaluation, process optimization and characterization of chickpea powder, J. Environ. Chem. Eng., 6 (2018) 6243–6255.
[17] A. Daverey, N. Tiwari, K. Dutta, Utilization of extracts of *Musa paradisica* (banana) peels and *Dolichos lablab* (Indian bean) seeds as low-cost natural coagulants for turbidity removal from water, Environ. Sci. Pollut. Res., 26 (2019) 34177–34183.
[18] M. Levi, J. Thachil, T. Iba, J.H. Levy, Coagulation abnormalities and thrombosis in patients with COVID-19, The Lancet Haematology, 7 (2020) e438–e440.
[19] S.N. Ugwu, A.F. Umuokoro, E.A. Echiegu, B.O. Ugwuishiwu, C.C. Enweremadu, Comparative study of the use of natural and artificial coagulants for the treatment of sullage (domestic wastewater), Cogent Eng., 4 (2017) 1365676, doi: 10.1080/23311916.2017.1365676.
[20] N.M. Mahmoodi, U. Sadeghi, A. Maleki, B. Hayati, F. Najafi, Synthesis of cationic polymeric adsorbent and dye removal isotherm, kinetic and thermodynamic, J. Ind. Eng. Chem., 20 (2014) 2745–2753.
[21] K. Mohajershojaei, N.M. Mahmoodi, A. Khosravi, Immobilization of laccase enzyme onto titania nanoparticle and decolorization of dyes from single and binary systems, Biotechnol. Bioprocess Eng., 20 (2015) 109–116.
[22] N.M. Mahmoodi, M. Arabloo, J. Abdi, Laccase immobilized manganese ferrite nanoparticle: synthesis and LSSVM intelligent modeling of decolorization, Water Res., 67 (2014) 216–226.
[23] J.V.M. Ribeiro, P.V. Andrade, A.G.D. Reis, *Moringa oleifera* seed as a natural coagulant to treat low-turbidity water by in-line filtration, Rev. Ambiente Agua, 14 (2019), doi: 10.4136/ambi-agua.2442.
[24] H. Kristianto, M.A Kurniawan, J.N. Soetedjo, Utilization of papaya seeds as natural coagulant for synthetic textile coloring agent wastewater treatment, Int. J. Adv. Sci. Eng. Inf. Technol., 8 (2018) 2071–2077.
[25] A. Baharin, N.A. Fattah, A.A. Bakar, Z.M. Ariff, Production of laminated natural fibre board from banana tree wastes, Procedia Chem., 19 (2016) 999–1006.
[26] M. Kandeeban, M. Malarkodi, Assessment of the farmers attitude towards banana cultivation and export in Coimbatore and Erode districts of Tamil Nadu, Int. J. Farm Sci., 9 (2019) 49–51.
[27] S.A. Aida, A. Noriza, M.M. Haswani, S.M.Y. Mya, A study on reducing fat content of fried banana chips using a sweet pretreatment technique, Int. Food Res. J., 23 (2016) 68–71.
[28] N.A. Oladoja, Headway on natural polymeric coagulants in water and wastewater treatment operations, J. Water Process Eng., 6 (2015) 174–192.
[29] S.D. Parvatham, N.R. Asha Rani, Evaluation of wastewater treatment using banana fruit peel powder as natural coagulant, Int. Res. J. Innovations Eng. Technol., 5 (2021) 58–65.
[30] K.R. Gunaratna, B. Garcia, S. Andersson, G. Dalhammar, Screening and evaluation of natural coagulants for water treatment, Water Sci. Technol. Water Supply, 7 (2007) 19–25.
[31] R. Musselman, Sampling Procedure for Lake or Stream Surface Water Chemistry, Res. Note RMRS-RN-49, Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2012.
[32] L.Z. Eng, K.P. Loo, Microwave-assisted extraction of banana peel bio-flocculant and its potential in wastewater treatment, Global J. Eng. Technol. Adv., 1 (2019) 1–9.
[33] S. Kamsonlian, S. Suresh, C.B. Majumder, S. Chand, Characterization of banana and orange peels: biosorption mechanism, Int. J. Sci. Technol., 2 (2011) 1–7.
[34] I. Kabenge, G. Omulo, N. Banadda, J. Seay, A. Zziwa, N. Kiggundu, Characterization of banana peels wastes as potential slow pyrolysis feedstock, J. Sustainable Dev., 11 (2018), doi: 10.5539/jsd.v11n2p14.
[35] N.M. Mokhtar, M. Priyatharishini, R.A. Kristanti, Study on the effectiveness of banana peel coagulant in turbidity reduction of synthetic wastewater, Int. J. Eng. Sci. Res. Technol., 6 (2019) 82–90.
[36] N. Gloria, Treatment of refinery and petrochemical wastewater using banana peel as a natural coagulant, Bioorg. Med. Chem., 7 (2018) 141–143.
[37] K.H. Chong, P.L. Kiew, Potential of banana peels as bio-flocculant for water clarification, Prog. Energy Environ., 1 (2017) 47–56.
[38] I.R. Yuliastri, E. Rohaeti, H. Effendi, L.K. Darusman, The use of *Moringa oleifera* seed powder as coagulant to improve the quality of wastewater and ground water, IOP Conf. Ser.: Earth Environ. Sci., 31 (2016), doi: 10.1088/1755-1315/31/1/012033.
[39] T. Zarei Mahmudabadi, A.A. Ebrahimi, H. Eslami, M. Mokhtari, M.H. Salmani, M.T. Ghaneian, M. Pakdaman, Optimization and economic evaluation of modified coagulation–flocculation

process for enhanced treatment of ceramic-tile industry wastewater, AMB Express, 8 (2018) 1–12.
[40] K. Cardoso Valverde, P. Ferri Coldebella, M. Fernandes Silva, L. Nishi, M. Carvalho Bongiovani, R. Bergamasco, *Moringa oleifera* Lam. and its potential association with aluminium sulphate in the process of coagulation/flocculation and sedimentation of surface water, Int. J. Chem. Eng., 2018 (2018) 4342938, doi: 10.1155/2018/4342938.
[41] A.H. Birima, H.A. Hammad, M.N.M. Desa, Z.C. Muda, Extraction of natural coagulant from peanut seeds for treatment of turbid water, IOP Conf. Ser.: Earth Environ. Sci., 16 (2013), doi: 10.1088/1755-1315/16/1/012065.
[42] M.F. Eskibalci, M.F. Ozkan, An investigation of the effect of NaCl concentration on the electrocoagulation of coal preparation plant tailings, Physicochem. Probl. Miner. Process., 54 (2018) 934–943.
[43] S. Adeel, M. Zuber, K.M. Zia, Microwave-assisted extraction and dyeing of chemical and bio-mordanted cotton fabric using harmal seeds as a source of natural dye, Environ. Sci. Pollut. Res., 25 (2018) 11100–11110.
[44] P.D. Pathak, S.A. Mandavgane, Preparation and characterization of raw and carbon from banana peel by microwave activation: application in citric acid adsorption, J. Environ. Chem. Eng., 3 (2015) 2435–2447.
[45] H.T. Vu, C.J. Scarlett, Q.V. Vuong, Maximising recovery of phenolic compounds and antioxidant properties from banana peel using microwave assisted extraction and water, J. Food Sci. Technol., 56 (2019) 1360–1370.
[46] A. Yimer, B. Dame, Papaya seed extract as coagulant for potable water treatment in the case of Tulte River for the community of Yekuset district, Ethiopia, Environ. Challenges, 4 (2021) 100198, doi: 10.1016/j.envc.2021.100198.
[47] Y. Li, J. Liu, Q. Yuan, H. Tang, F. Yu, X. Lv, A green adsorbent derived from banana peel for highly effective removal of heavy metal ions from water, RSC Adv., 6 (2016) 45041–45048.
[48] S. Sasikala, G. Muthuraman, Turbidity removal from surface water by natural coagulants and its potential application, Iran. J. Energy Environ., 8 (2017) 61–66.
[49] F.A. Dawodu, C.J. Abonyi, K.G. Akpomie, Feldspar-banana peel composite adsorbent for efficient crude oil removal from solution, Appl. Water Sci., 11 (2021) 1–10.
[50] V.S. Munagapati, V. Yarramuthi, Y. Kim, K.M. Lee, D.S. Kim, Removal of anionic dyes (Reactive Black 5 and Congo red) from aqueous solutions using banana peel powder as an adsorbent, Ecotoxicol. Environ. Saf., 148 (2018) 601–607.
[51] N.A.N. Muhamad, N.F. Juhari, I.N. Mohamad, Efficiency of natural plant-based coagulants for water treatment, IOP Conf. Ser.: Earth Environ. Sci., 616 (2020), doi: 10.1088/1755-1315/616/1/012075.
[52] G.H. Ali, B.E. Hegazy, H.A. Fouad, M. Rehab, Comparative study on natural products used for pollutants removal from water, J. Appl. Sci. Res., 5 (2008) 1020–1029.
[53] S. Boulaadjoul, H. Zemmouri, Z. Bendjama, N. Drouiche, A novel use of *Moringa oleifera* seed powder in enhancing the primary treatment of paper mill effluent, Chemosphere, 206 (2018) 142–149.
[54] A. Al-Mamun, A.T.A. Basir, White popinac as potential phyto-coagulant to reduce turbidity of river water, ARPN J. Eng. Appl. Sci., 11 (2016) 7180–7183.
[55] A.S. Mukheled, A novel water pretreatment approach for turbidity removal using date seeds and pollen sheath, J. Water Resour. Prot., 4 (2012), doi: 10.4236/jwarp.2012.42010.
[56] M. Priyatharishini, N.M. Mokhtar, Performance of jackfruit (*Artocarpus heterophyllus*) peel coagulant in turbidity reduction under different pH of wastewater, Mater. Today Proc., 46 (2021) 1818–1823.
[57] S. Maurya, A. Daverey, Evaluation of plant-based natural coagulants for municipal wastewater treatment, 3 Biotech, 8 (2018) 1–4.
[58] G. Vilardi, L. Di Palma, N. Verdone, Heavy metals adsorption by banana peels micro-powder: equilibrium modeling by non-linear models, Chin. J. Chem. Eng., 26 (2018) 455–464.
[59] M. Lapointe, I. Papineau, S. Peldszus, N. Peleato, B. Barbeau, Identifying the best coagulant for simultaneous water treatment objectives: interactions of mononuclear and polynuclear aluminum species with different natural organic matter fractions, J. Water Process Eng., 40 (2021) 101829, doi: 10.1016/j.jwpe.2020.101829.
[60] S Water and World Health Organization, Guidelines for Drinking-Water Quality [Electronic Resource]: Incorporating First Addendum, Vol. 1, Recommendations, 2006.
[61] N.K. Mondal, S. Kar, Potentiality of banana peel for the removal of Congo red dye from aqueous solution: isotherm, kinetics and thermodynamics studies, Appl. Water Sci., 8 (2018) 1–12.