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Study on the Effectiveness of Banana Peel and Moringa Oleifera Seed as Natural Coagulant for the Treatment of Synthetic Turbid Water

Nurain Mohd Khairi[1], Nor Hazren Abdul Hamid[1*]

[1] *Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: norhazren@uthm.edu.my
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Abstract

The extensive use of chemical coagulants in conventional water treatment has raised concerns related to environmental sustainability, sludge generation, and residual chemical content. This study evaluated and compared the performance of banana peel powder and Moringa oleifera seed powder as natural coagulants for turbidity removal in synthetic turbid water and real river water. Fourier Transform Infrared Spectroscopy (FTIR) analysis identified functional groups responsible for charge neutralization and adsorption, while Field Emission Scanning Electron Microscopy (FESEM) revealed distinct surface morphologies of both coagulants. Synthetic water with an initial turbidity of approximately 85 NTU, representing Class III river water under the National Water Quality Standards (NWQS), was treated using standard jar test procedures. The effects of coagulant dosage, slow mixing speed, and settling time were systematically investigated to determine optimum operating conditions. These optimum conditions were subsequently applied to Panchor River water to assess practical applicability, resulting in a significant reduction in turbidity and demonstrating the feasibility of translating laboratory-scale findings to real water treatment. The optimum dosage for Moringa oleifera seed powder was 2.0 g/L, achieving a maximum turbidity removal efficiency of approximately 96.45% at a slow mixing speed of 20 rpm and a settling time of 150 minutes. In contrast, banana peel powder achieved an optimum turbidity removal efficiency of approximately 63.69% at the same dosage of 2.0 g/L, with a slow mixing speed of 60 rpm and a settling time of 150 minutes. Overall, Moringa oleifera seed powder exhibited significantly higher turbidity removal efficiency, while both materials demonstrate potential as sustainable and environmentally friendly alternatives to chemical coagulants.

1. Introduction

Water is one of the most essential natural resources for sustaining human life, ecological balance, and socio-economic development. Although approximately 71% of the Earth's surface is covered by water, only a small fraction is available as freshwater suitable for human consumption. Despite the apparent abundance of water resources, surface water quality has deteriorated significantly due to increasing anthropogenic activities. Rapid population growth, urbanization, industrial expansion, and intensive agricultural practices have contributed to the discharge of untreated wastewater, agricultural runoff, and industrial effluents into rivers [1]. In Malaysia, river pollution has become a critical concern, with many rivers classified as polluted or slightly polluted due to elevated levels of suspended solids, organic matter, and microbiological contaminants [2].

One of the most important indicators of surface water pollution is turbidity, which reflects the presence of suspended and colloidal particles in water. High turbidity not only reduces water clarity but also interferes with disinfection processes and provides a medium for pathogen survival, thereby posing serious health risks [3]. Furthermore, treating highly turbid water increases operational complexity and treatment costs, underscoring the need for efficient coagulation processes to ensure the production of safe drinking water.

Conventional water treatment systems commonly employ chemical coagulants such as aluminium sulfate (alum) during the coagulation–flocculation stage due to their proven effectiveness and low initial cost [4]. However, the extensive use of alum has raised significant concerns regarding its environmental, operational, and health implications. Residual aluminium in treated water has been associated with potential long-term health risks, including neurological disorders such as Alzheimer's disease [5]. In addition to health concerns, chemical coagulation generates large volumes of non-biodegradable sludge that require specialized handling and disposal. Improper sludge management can lead to secondary pollution of soil and water bodies, increasing the environmental footprint of conventional water treatment processes [3][6].

In response to these challenges, there has been growing interest in the use of natural, plant-based coagulants as sustainable alternatives to chemical coagulants. Natural coagulants derived from agricultural waste are biodegradable, less toxic, and capable of producing lower sludge volumes, making them more environmentally friendly [7][8]. Their local availability and low cost further enhance their suitability for decentralized and rural water treatment applications.

Banana peel powder has emerged as a promising natural coagulant due to its high content of biopolymers such as pectin, cellulose, and lignin, which possess functional groups capable of adsorbing and bridging suspended particles [9][10]. As an abundant agricultural waste in Malaysia, banana peels offer an environmentally beneficial option for water treatment while simultaneously addressing waste management issues. Similarly, Moringa oleifera seed powder is well known for its water-soluble cationic proteins, which effectively neutralize negatively charged colloidal particles and have demonstrated high turbidity removal efficiency in numerous studies.

Although both banana peel powder and Moringa oleifera seed powder have individually shown promising coagulation performance, direct comparative studies conducted under identical operating conditions remain limited. Furthermore, most existing studies focus on either synthetic or real water samples independently, resulting in limited understanding of their comparative effectiveness under controlled laboratory conditions and practical applications. This gap highlights the need for a systematic comparison of these two natural coagulants using standardized treatment parameters.

Therefore, the main objective of this study is to compare the effectiveness of banana peel powder and Moringa oleifera seed powder as natural coagulants for water treatment. Specifically, this study aims to characterize the functional groups and surface morphology of both coagulants using Fourier Transform Infrared Spectroscopy (FTIR) and Field Emission Scanning Electron Microscopy (FESEM), determine their optimum operating conditions including dosage, slow mixing speed, and settling time based on turbidity removal efficiency, and evaluate their performance when applied to real river water samples.

The scope of this study is limited to laboratory-scale evaluation focusing primarily on turbidity removal. Synthetic turbid water with an initial turbidity of approximately 85 NTU will be prepared using kaolin powder, followed by jar test experiments to optimize treatment parameters. The optimized conditions will then be applied to real river water samples to assess practical performance. Other water quality parameters and long-term treatment performance are beyond the scope of this research. Overall, this study is significant in advancing sustainable and eco-friendly water treatment practices by promoting the use of locally available, low-cost natural coagulants, particularly for rural and small-scale water treatment systems where access to chemical coagulants and advanced infrastructure is limited.

2. Materials and Methodology

Banana peel powder used in this study was prepared from banana peels obtained from local agricultural waste sources, specifically collected from a roadside pisang goreng stall in Bukit Pasir, Johor. Moringa oleifera seeds were sourced from a local resident in a village area in Seremban, Negeri Sembilan, to ensure freshness and support the use of readily available natural materials. Synthetic turbid water was prepared using kaolin powder to simulate suspended solids commonly present in surface water, as kaolin is widely used in coagulation studies. The experimental work was conducted at the Environmental Engineering Technology Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM), to compare the coagulation performance of banana peel powder and Moringa oleifera seed powder as natural coagulants for water treatment applications.

2.1 Preparation of Banana Peel Powder and Moringa Oleifera Seed Powder

The collected banana peels were thoroughly washed with distilled water to remove adhering impurities and subsequently oven-dried at 80 °C for 24 h to reduce moisture content and enhance storage stability. Moringa oleifera seeds were manually dehulled to separate the outer seed coat from the inner kernel before drying. The dried banana peels and moringa seed kernels were then ground using a laboratory grinder to obtain a fine and homogeneous powder. The resulting powders were sieved using a fine mesh sieve to ensure uniform particle size, thereby improving consistency and reproducibility during the coagulation experiments.

(a) **(b)**

Figure 1: *(a) banana peel powder; (b) Moringa oleifera seed powder*

2.2 Preparation of Synthetic Turbid Water

Synthetic turbid water was prepared in this study using kaolin powder as the turbidity-inducing agent to simulate suspended solids commonly found in polluted natural water sources. Kaolin powder was selected due to its chemical stability, fine particle size, and ability to generate consistent turbidity levels, making it suitable for controlled laboratory coagulation–flocculation experiments. In this study, synthetic water with a turbidity level of approximately 85 NTU was prepared to represent moderate turbidity conditions, which are generally associated with Class III of the National Water Quality Standards (NWQS). Adequate mixing is essential to prevent particle aggregation and to achieve a stable and homogeneous turbidity level. The resulting turbidity was measured and confirmed using a calibrated turbidity meter. Synthetic turbid water was freshly prepared prior to each experiment to maintain consistency and reliability across all experimental trials.

2.3 Water Sampling in Panchor River

The grab sampling method was employed for river water collection in accordance with the procedures recommended by APHA et al. (2012). River water samples were collected from Panchor River, located in Pagoh, Johor, Malaysia. To ensure representativeness of the river conditions, samples were collected from selected points along the river with consideration given to spatial variation. Sampling was conducted using clean and sterilised polyethylene bottles. Water samples were collected by gently immersing the bottles below the surface while avoiding surface debris. The bottles were immediately capped after collection to prevent contamination and sample loss.

2.4 Jar Test Experiment

Jar test experiments were conducted to evaluate the coagulation–flocculation performance of banana peel powder and Moringa oleifera seed powder using synthetic turbid water under controlled laboratory conditions. A standard jar test apparatus was used to simulate conventional water treatment processes. For each experimental run, 500 mL of synthetic turbid water with an initial turbidity of approximately 85 NTU was placed in a 1 L beaker, allowing sufficient headspace for effective mixing while maintaining consistency. All experiments were carried out at room temperature. To enhance solubility and ensure uniform dispersion of the active coagulating components, coagulant extract solutions were prepared instead of directly adding powdered materials to the water samples. A predetermined amount of banana peel powder or Moringa oleifera seed powder was mixed with distilled water using a magnetic stirrer until a homogeneous solution was obtained, followed by filtration to remove undissolved particles; only the clear supernatant was subsequently used as the coagulant solution during the jar test experiments.

(a) (b)

Figure 2: *Extracted solution from (a) banana peels powder and (b) Moringa oleifera seed powder*

The required volume of coagulant extract solution was then added to each beaker based on the selected dosage parameter. As to determine the effect of coagulant dosage, the banana peel powder and moringa oleifera seed powder dosage was varied between (0.5, 1.0, 1.5, 2.0 and 2.5 g/L). Contrarily, to determine the effect of settling time, by using the optimum dosage for banana peel powder and moringa oleifera seed powder with various settling time (30 min, 60 min, 90 min, 120 min and 150 min). Upon addition of the coagulant extract, rapid mixing 180 rpm for 5 minutes was immediately initiated to ensure uniform distribution of the coagulant throughout the water sample. This was followed by slow mixing with 60 rpm for 20 minutes to promote floc formation and growth.

Another jar test experiment for the effect of mixing speed (slow mixing), using optimum dosage and settling time was conducted. The stirring speed was subjected to three effects of slow mixing (20, 40 and 60 rpm). During settling, 50 mL of the water sample were withdrawn using pipette without agitating the sediment flocs. removal efficiency is calculated using the standard formula:

$$\text{Turbidity Removal } (\%) = (Ti - Tf)/Ti \times 100 \quad \textbf{(1)}$$

where Ti and Tf represent the initial and final turbidity values, respectively.

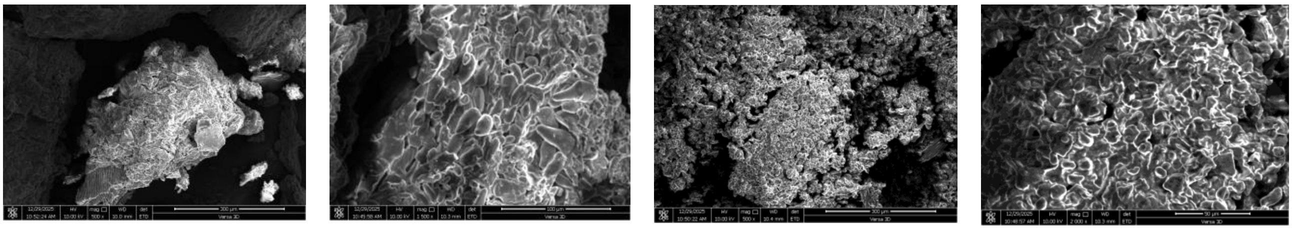
2.5 FESEM and FTIR Analysis of Banana Peel Powder and Moringa Oleifera Seed Powder

The surface morphology of banana peel powder and Moringa oleifera seed powder prior to the coagulation process was characterized using Field Emission Scanning Electron Microscopy (FESEM). The analysis was performed to obtain high-resolution microstructural images. In addition, the functional groups present in both banana peel powder and moringa seed powder were analyzed using Fourier Transform Infrared Spectroscopy (FTIR).

3. Result and Discussion

3.1 Characterization of Banana Peel Powder and Moringa Oleifera Seed Powder

Figure 3 the surface morphology for the banana peel powder and *Moringa oleifera* seed powder. The observed surface morphology and functional groups are consistent with findings reported in previous studies on plant-based coagulants. Similar rough, porous, and irregular structures in banana peel-derived materials have been shown to enhance adsorption and particle bridging during coagulation processes [9]. Surface roughness and micro void dispersion throughout the particles are more visible due to the higher magnification. These microstructural characteristics indicate a larger microscale surface area, which could enhance inter-particle contact and adsorption during the coagulation–flocculation process [11]. Likewise, the compact morphology and prominent amide functional groups identified in Moringa oleifera seed powder support earlier reports attributing its high turbidity removal efficiency to protein-based charge neutralization mechanisms [12]. The particles have sharper particle outlines, less big spaces, and a more uniform, densely packed appearance than banana peel powder. Although the degree of fragmentation is less noticeable, the surface texture is still harsh. The rough and porous morphology also suggests a strong adsorption capability, as colloidal particles can be trapped within surface voids and pores [13]. The observed surface characteristics demonstrate that Moringa oleifera seed powder possesses favorable physical properties for coagulation application. The presence of pores, rough textures, and irregular particle shapes enhances adsorption, particle destabilization, and floc formation.



(a) (b) (c) (d)

Figure 3: *Surface morphology of (a)(b) banana peel powder and (c)(d) Moringa oleifera seed powder*

As shown in Figure 4, both spectra exhibit broad O–H stretching bands in the region of 3200–3400 cm^{-1}, indicating the presence of hydroxyl groups in both materials. Peaks around 2920 cm^{-1} corresponding to C–H stretching vibrations are also present in both spectra, suggesting similar organic structures. However, Moringa oleifera seed powder shows more pronounced amide-related peaks near 1640 cm^{-1}, indicating a higher protein content compared to banana peel powder. In contrast, banana peel powder exhibits stronger absorption in the 1000–1100 cm^{-1} region, which is associated with polysaccharides and cellulose components. These differences suggest that Moringa oleifera seed powder primarily facilitates coagulation through protein-based charge neutralization, while banana peel powder relies more on adsorption and bridging mechanisms due to its polysaccharide-rich structure [14]. The presence of complementary functional groups in both materials highlights their potential effectiveness as natural coagulants in water treatment applications.

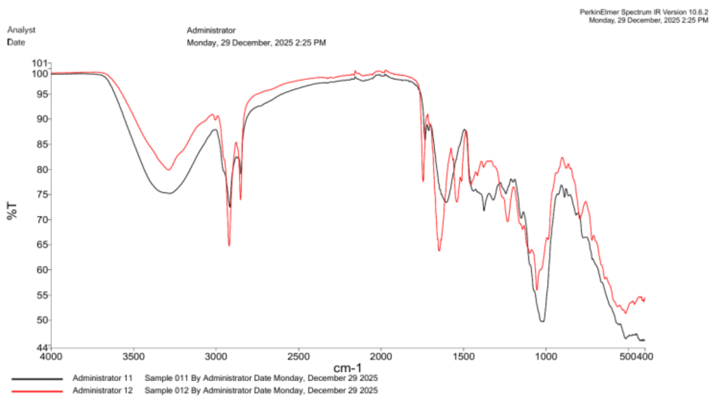


Figure 4: *FTIR spectrum of Banana Peel Powder comparing to Moringa Oleifera Seed Powder*

3.2 Factors Affecting the Coagulation Process

3.2.1 Effect of coagulant dosage

The synthetic turbid water prepared using kaolin powder was treated with varying dosages of banana peel powder and Moringa oleifera seed powder to evaluate their effectiveness as natural coagulants in turbidity removal. The dosages applied in this study were 0.5 g/L, 1.0 g/L, 1.5 g/L, 2.0 g/L, and 2.5 g/L, while untreated samples were used as the control for comparison purposes. Each beaker was dosed with a specific amount of coagulant to examine the influence of dosage variation on the coagulation–flocculation process and the resulting turbidity reduction. The graph in figure 5 illustrates the relationship between coagulant dosage (g/L) and final turbidity level (NTU) for banana peel powder and Moringa oleifera seed powder. For banana peel powder, the turbidity level shows a significant decrease as the dosage increases from 0 g/L to 2.0 g/L. The untreated sample recorded the highest turbidity value of 85.1 NTU, while the lowest turbidity value of 27.6 NTU was observed at a dosage of 2.0 g/L. This indicates that increasing the dosage of banana peel powder enhances particle destabilisation and floc formation, leading to more effective turbidity removal. However, when the dosage was further increased to 2.5 g/L, the turbidity level increased slightly to 29.2 NTU. This suggests that the optimum dosage for banana peel powder is approximately 2.0 g/L. For Moringa oleifera seed powder, a rapid reduction in turbidity was observed at lower dosages, with turbidity decreasing sharply from 85.1 NTU to 32.1 NTU at 0.5 g/L. The turbidity level then fluctuated slightly with increasing dosage, reaching the its lowest value of 27.9 NTU at a dosage of 2.0 g/L. This indicates that Moringa oleifera seed powder is effective in turbidity removal even at relatively low dosages, although the optimum performance was achieved at 2.0 g/L. At a higher dosage of 2.5 g/L, the turbidity increased to 30.1 NTU, indicating a decline in treatment efficiency [12]. Similar as previous research has shown that overdosing natural coagulants can lead to particle restabilization and reduced removal efficiency, a behavior also reported for Moringa oleifera seed extracts and other biopolymer-based coagulants [12][15].

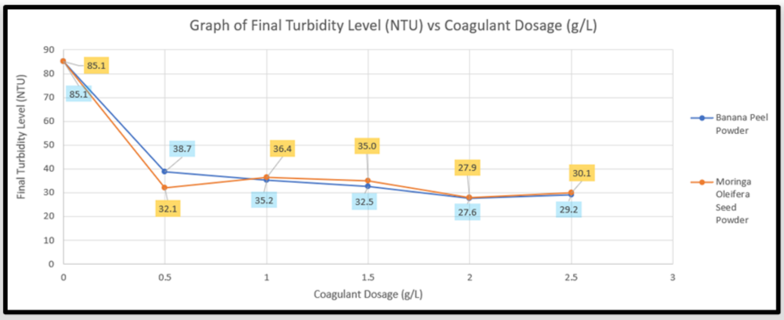


Figure 5: *Final Turbidity level of synthetic solution (kaolin) against coagulant dosages used for coagulation*

3.2.2 Effect of Settling Time

The effect of settling time on turbidity removal was investigated to evaluate the settling behaviour of flocs formed using banana peel powder and Moringa oleifera seed powder. Settling time is an important parameter in the coagulation–flocculation process, as it determines the duration allowed for destabilised particles to aggregate into larger flocs and settle under gravity. In this study, settling times of 30, 60, 90, 120, and 150 minutes were examined to assess their influence on the final turbidity level. The experiment was conducted using an optimum coagulant dosage of 2.0 g/L for both banana peel powder and Moringa oleifera seed powder, as determined from the dosage variation study. The graph in Figure 6 illustrates the variation of final turbidity level with settling time for banana peel powder and Moringa oleifera seed powder at a constant dosage of 2.0 g/L. For banana peel powder, the turbidity level decreased gradually as the settling time increased from 30 to 150 minutes. The turbidity value reduced from 24.6 NTU at 30 minutes to 21.7 NTU at 150 minutes, indicating continuous improvement in turbidity removal with longer settling time. For Moringa oleifera seed powder, a more pronounced reduction in turbidity was observed with increasing settling time. The turbidity level decreased significantly from 45.2 NTU at 30 minutes to 26.3 NTU at 120 minutes, followed by a further reduction to 22.4 NTU at 150 minutes. Although both coagulants achieved their lowest turbidity values at 150 minutes, the improvement beyond 120 minutes was relatively small, indicating that a settling time between 120 and 150 minutes is sufficient for effective turbidity removal. These findings highlight the importance of optimising settling time to balance treatment efficiency and operational practicality in water treatment processes [12][15].

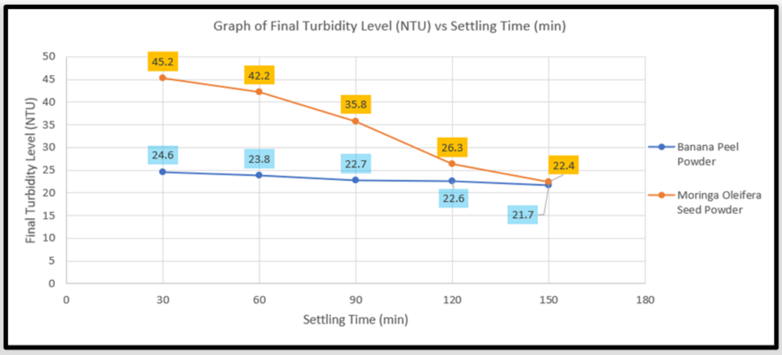


Figure 6: *Final Turbidity level of synthetic solution (kaolin) against settling time used for coagulation*

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3.2.3 Effect of Stirring Speed (slow mixing)

The next parameter investigated in this study is the stirring speed (slow mixing) during the coagulation process. Slow mixing speeds of 20 rpm, 40 rpm, and 60 rpm were applied while maintaining a constant coagulant dosage of 2.0 g/L and a settling time of 150 minutes. The slow mixing stage is critical because it promotes the formation, growth, and stabilization of flocs after the initial rapid mixing stage. Unlike rapid mixing, which is mainly used to uniformly disperse the coagulant and initiate charge neutralization, slow mixing provides gentle agitation that allows destabilized particles to collide and aggregate into larger flocs without breaking them [16][17]. Figure 7 illustrates the relationship between final turbidity level (NTU) and slow mixing speed (rpm) for both banana peel powder and Moringa oleifera seed powder. For banana peel powder, the graph shows a slight increase in turbidity from 20 rpm to 40 rpm, followed by a decrease at 60 rpm. In contrast, Moringa oleifera seed powder displays a more pronounced trend in the graph. The turbidity is lowest at 20 rpm, indicating highly effective floc formation under gentle mixing conditions. As the slow mixing speed increases to 40 rpm and 60 rpm, the turbidity rises significantly, implying that higher shear forces disrupt the flocs formed by Moringa oleifera. Overall, the graph demonstrates that slow mixing speed plays a crucial role in coagulation performance, particularly for Moringa oleifera seed powder. In addition, the improved performance under gentle slow mixing conditions is consistent with findings, who emphasized that excessive shear forces can disrupt floc integrity and hinder settling efficiency [6][17]. Gentle slow mixing favors the formation of larger and stronger flocs, leading to better turbidity removal [15][18]. Excessive slow mixing, however, can break flocs apart, reducing settling efficiency and resulting in higher residual turbidity.

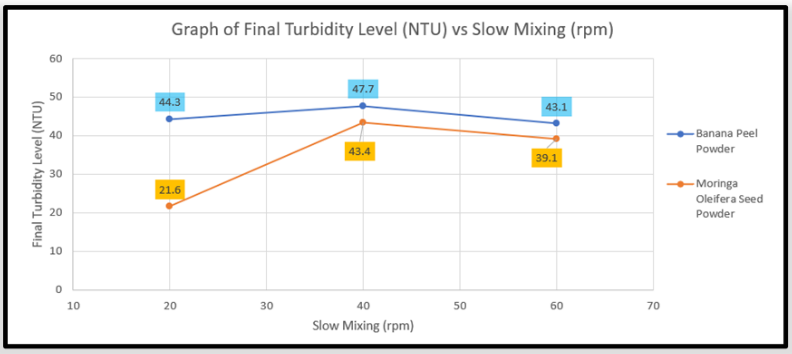

Figure 7: *Final Turbidity level of synthetic solution (kaolin) against stirring speed (slow mixing) used for coagulation*

3.3 Analysis of Optimum Condition on River Water

The optimum conditions obtained from synthetic water experiments, including dosage, stirring speed (slow mixing) and settling time, were applied to river water to assess their practical effectiveness. This analysis aims to evaluate how well the selected natural coagulants banana peel powder and Moringa oleifera seed powder perform in real water conditions, where the composition and turbidity levels are more complex than in laboratory-prepared samples. The initial turbidity of Panchor River are 119 NTU. Table 1 presents the final turbidity and percentage removal of Panchor River water after treatment using the optimum operating conditions for each natural coagulant. The table summarizes the performance of both coagulants at a fixed dosage of 2.0 g/L and a settling time of 150 minutes, while applying their respective optimum slow mixing speeds. Based on Table 1, banana peel powder achieved a final turbidity of 43.2 NTU with a percentage removal of 63.69% when operated at an optimum slow mixing speed of 60 rpm. This result indicates that banana peel powder is capable of reducing turbidity in river water, but its removal efficiency is moderate. The relatively high final turbidity suggests that the flocs formed may be less dense or less stable, resulting in incomplete settling of suspended particles. In contrast, Moringa oleifera seed powder demonstrated significantly better performance, producing a much lower final turbidity of 4.23 NTU and a high percentage removal of 96.45% at an optimum slow mixing speed of 20 rpm. This highlights the superior coagulation efficiency of Moringa oleifera, particularly under gentle slow mixing conditions. The superior performance of *Moringa oleifera* seed powder in real river water is consistent with previous comparative studies, which reported turbidity removal efficiencies exceeding 90% under optimized conditions [12][13]. In contrast, the moderate efficiency observed for banana peel powder agrees with earlier findings indicating that adsorption- and bridging-based coagulants are more sensitive to complex water matrices containing natural organic matter and competing ions [9][15].

Coagulant	Dosage (g/L)	Stirring speed (slow mixing) (rpm)	Settling time (min)	Final Turbidity (NTU)	Percentage removal (%)
Banana Peel Powder	2.0	60	150	43.2	63.69
Moringa Oleifera Seed Powder	2.0	20	150	4.23	96.45

Table 1: *Final Turbidity and Percentage Removal of Panchor River Water after treatment with optimum condition parameter using Banana Peel Powder and Moringa Oleifera Seed Powder.*

4. Conclusion

This study successfully evaluated and compared the effectiveness of banana peel powder and Moringa oleifera seed powder as natural coagulants for treating synthetic turbid water and real river water samples. Characterization using Fourier Transform Infrared Spectroscopy (FTIR) confirmed the presence of functional groups essential for coagulation mechanisms in both materials. Banana peel powder contained hydroxyl and carboxyl groups associated with biopolymers such as pectin, cellulose, and lignin, which promote adsorption and particle bridging, while Moringa oleifera seed powder exhibited strong functional peaks related to water-soluble cationic proteins responsible for charge neutralization. Field Emission Scanning Electron Microscopy (FESEM) analysis further supported these findings by revealing a porous and irregular surface morphology for banana peel powder, providing a large surface area for floc formation, whereas Moringa oleifera seed powder displayed a smoother and more compact structure consistent with its protein-based coagulation mechanism. Jar test experiments using synthetic turbid water with an initial turbidity of approximately 85 NTU, representing Class III river water under the National Water Quality Standards (NWQS), demonstrated that both coagulants achieved substantial turbidity reduction under optimized conditions. Turbidity removal efficiency was strongly influenced by coagulant dosage, slow mixing speed, and settling time, with overdosing leading to reduced performance due to particle restabilization. Moringa oleifera seed powder showed significantly higher efficiency due to its protein-based charge neutralization mechanism, while banana peel powder provided moderate removal through adsorption and bridging. The results confirm the feasibility of using locally available, biodegradable materials as alternatives to chemical coagulants. Future studies should focus on optimizing extraction methods, evaluating other water quality parameters, and assessing long-term performance in full-scale applications.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review.

References

[1] World Health Organization. (2017). Guidelines for drinking-water quality (4th ed.). WHO Press. https://www.who.int

[2] Department of Environment Malaysia. (2022). Annual report: Water quality monitoring and pollution control. Department of Environment Malaysia.

[3] Zaidi, S. Z. (2019). Coagulation-flocculation process for turbidity removal using eco-friendly coagulants. International Journal of Environmental Science and Technology, 16(7), 3239–3250.

[4] Tahraoui, H., Toumi, S., Boudoukhani, M., Touzout, N., Sid, A. N. E. H., Amrane, A., Belhadj, A. E., Hadjadj, M., & Laichi, Y. (2024). Evaluating the effectiveness of coagulation–flocculation treatment using aluminum sulfate on a polluted surface water source: A year-long study. Water, 16(3), 400. https://doi.org/10.3390/w16030400

[5] Krupińska, I. (2020). Aluminium residuals in drinking water and health risk assessment: A critical review. Ecological Chemistry and Engineering S, 27(1), 111–122.

[6] Matouq, M., Al-Anber, Z., & Alkhateeb, S. (2021). Optimization of natural coagulant dosage and pH in water treatment using agricultural waste. Water Science & Technology, 84(4), 866–875.
[7] Singh, S., & Yadav, A. (2020). Water quality standards and classification of rivers in Malaysia. Asian Journal of Water, Environment and Pollution, 17(3), 1–8.
[8] Mat Ali, N., & Ismail, W. N. A. (2024). Green chemistry approaches in water treatment using local plant-based coagulants. Sustainable Chemistry & Pharmacy, 31, 101063.
[9] Kabange, N. R., & Nyenje, P. (2021). Evaluation of banana peel biopolymer as a natural coagulant for turbid water treatment. Water Supply, 21(4), 1560–1571. https://doi.org/10.2166/ws.2021.026
[10] Rayer, M. I., Jamaluddin, N., & Rosli, N. A. (2024). Characterization and application of banana peel for sustainable water treatment. Environmental Pollution and Control, 39(1), 88–97.
[11] Preparation of Cellulose Adsorbent Based on Banana Peel Waste (Musa paradisiaca): Green Activation and Adsorption of Rhodamine B from the Aquatic Environment. (2024). Journal of Environmental Chemical Engineering. https://www.sciencedirect.com/science/article/abs/pii/S2352507X2400057X
[12] Desta, W. M. (2021). Wastewater treatment using a natural coagulant (Moringa oleifera seeds): Optimization through response surface methodology. Heliyon, 7(9), e08451. https://doi.org/10.1016/j.heliyon.2021.e08451
[13] Naveendre Vel & Nor Hazren Binti Abdul Hamid. (2025). Comparative Study of Alum and Moringa Oleifera Seed Powder in Turbidity Removal from River Water and Synthetic Solution (Kaolin). Progress in Engineering Application and Technology, 6(2), 15–22. https://penerbit.uthm.edu.my/periodicals/index.php/peat/article/view/21068
[14] Enhancing the Efficiency of Banana Peel Bio-Coagulant in Turbid and River Water Treatment Applications. (2024). Water, 14(16), 2473. https://www.mdpi.com/2073-4441/14/16/2473
[15] Yang, R., Li, H., Huang, M., Yang, H., & Li, A. (2022). A review on chitosan-based flocculants and their applications in water treatment. Water Research, 215, 118261. https://doi.org/10.1016/j.watres.2022.118261
[16] Teh, C. Y., Budiman, P. M., Shak, K. P. Y., & Wu, T. Y. (2023). Recent advancement of coagulation–flocculation and its application in wastewater treatment. Water, 15(3), 521. https://doi.org/10.3390/w15030521
[17] Renault, F., Sancey, B., Badot, P. M., & Crini, G. (2020). Chitosan for coagulation/flocculation processes – An eco-friendly approach. European Polymer Journal, 138, 109961. https://doi.org/10.1016/j.eurpolymj.2020.109961
[18] Choy, S. Y., Prasad, K. M. N., Wu, T. Y., Raghunandan, M. E., & Ramanan, R. N. (2021). Performance of conventional starches as natural coagulants for turbidity removal. Journal of Environmental Management, 283, 111939. https://doi.org/10.1016/j.jenvman.2021.111939