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To cite this article: Nor Sakinah Mohd Said *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1548** 012033

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Seeds of *Leucaena leucocephala* and *Bauhinia purpurea* as sustainable remediator of suspended solids in wastewater

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Abstract. Total suspended solids (TSS) in wastewater pose a significant environmental concern, affecting water quality deterioration. It is often associated with organic and inorganic pollutants, disrupting aquatic ecosystems and hinder downstream water treatment processes. Coffee processing mill effluent (CPME) is one of the underexplored agro-industrial effluent with high TSS content, with growing concern of water pollution due to low awareness of the smallholders. Coagulation-flocculation is a widely used preliminary treatment technique, though most studies have focused on chemical-based coagulants. While conventional coagulants are effective, they pose risks such as chemical residues, excessive sludge generation, and environmental toxicity, prompting a need for greener alternatives like natural coagulants. This study aimed to evaluate the performance of natural plant-based coagulants prepared from two locally available tropical species in Malaysia; *Leucaena leucocephala* and *Bauhinia purpurea*, using a chemical-free water extraction method. Jar test experiments were conducted to assess removal efficiency of TSS, alongside pH stability, under varying coagulant dosages. The results showed that both plant extracts demonstrated notable coagulation activity, with *Leucaena leucocephala* achieving up to 49% TSS removal at a low dosage and minimal pH disturbance. These findings highlight the potential of using untreated plant materials as sustainable, eco-friendly alternatives to chemical coagulants in CPME treatment.

1. Introduction

Urbanization and industrial activities have led to numerous environmental pollution concerns, with this research specifically addressing wastewater pollution. Estimated 80% of global wastewater is discharged untreated into the environment, posing serious risks to aquatic ecosystems and public health (UNESCO, 2023). The coagulation-flocculation treatment is an established preliminary wastewater treatment, especially in removing suspended solids which might consist of organic matter or other toxic pollutants, according to the variety of wastewater (Okoro et al., 2021). In common practice, chemical coagulants are used due to its high efficiency and proven working mechanism but come with some limitations. Besides limitation due to its high



acquisition cost and large volumes of sludge, conventionally used chemical coagulant such as aluminium and ferric sulphate pose ecological and health threats (Okoro et al., 2021). This had led to rising attention in exploring environmentally friendly alternatives such as natural coagulants, which not only reduce turbidity effectively but also minimize chemical residues in treated water (Zaidi et al., 2022). Natural coagulants can be derived from various sources, including plant materials (seeds, leaves, roots, and fruit peels), animal-based biopolymers (such as chitosan and gelatine), microbial exopolysaccharides, and naturally occurring minerals like clays and zeolites (Ahmad et al., 2021; Yin, 2010). Plant-based natural coagulants have received the most research attention due to their widespread availability, ease of preparation and handling, and cost-effectiveness. The main components contributing to their coagulation efficiency are proteins and polysaccharides, which aid in charge neutralization and bridging mechanisms during floc formation (Yin, 2010).

Some approaches had been highlighted to extract those active compounds from plants which are alcohol, salt and water extraction which then can be further purified to enhance their performance; that have been thoroughly detailed in our previous literature review (Kurniawan et al., 2023). A study by Madrona et al. (2010) shown that seed of *Moringa oleifera* extracted using saline solution of 1 M KCl gave better protein content (23 400 mg/L), thus, better treatment efficiency (96% turbidity and 82% colour removal) than water-extracted coagulant with only 873 mg/L protein (52% turbidity and 33% colour removal). While those chemically alcohol and salt extracted coagulant reported to extract the active compounds more effectively, it may still leave a chemical residue that compromise the sustainability of the treatment. A study by Ahmad et al. (2024) explored on the efficiency of plant-based coagulant prepared through water extraction. A mixture of neem, cassava and wild betel leaves showed removal efficiency over 80% for both turbidity and total suspended solids (TSS), and 50% of colour and chemical oxygen demand (COD). Seeds of *Moringa oleifera* is one of the commons plants used for these purposes. The use of natural coagulants also results in less sludge production, simplifying disposal management and offering potential as a valuable by-product for resource reclamation (Dash et al., 2024). Moreover, several studies report that plant-based coagulants do not significantly alter water pH, unlike many chemical coagulants, which can lead to corrosive or acidic discharge conditions (Okoro et al., 2021).

Existing literature on natural coagulants often focuses on a single plant species for the treatment of specific types of wastewaters, and reports on the application of natural coagulants for coffee processing mill effluent (CPME) are particularly limited. CPME is characterized by high organic content, turbidity, and acidity, posing serious treatment challenges and environmental risks if discharged untreated (Said et al., 2023). Therefore, this research adopted a new approach by comparing the coagulation performance of natural coagulants prepared from two local plant species, *Leucaena leucocephala* and *Bauhinia purpurea*, which are easily accessible and widely propagated in Malaysia. In addition to that, the chemical-free preparation employed in this study ensures minimal environmental impact, safeguarding human well-being. This is aligned with global initiative on sustainability as highlighted in Sustainable Development Goals (SDGs) especially SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate action), SDG 14 (Life Below Water), SDG 3 (Good Health and Well-being) and SDG 15 (Life on Land). In conclusion, this study aims to evaluate and compare the coagulation performance of *Leucaena leucocephala* and *Bauhinia purpurea* extracts in treating CPME, using a chemical-free extraction approach. To the authors' knowledge, no comparative

study has investigated these two species for CPME treatment using a sustainable, chemical-free approach.

2. Materials and methods

2.1 Collection and characterization of wastewater

Real coffee processing effluent was obtained from a coffee processing plant in Pulau Pinang, Malaysia. It was collected in a 1 000 L container through pump suction from its wastewater collection point. The collected wastewater was then stored in a greenhouse at 37°C in Universiti Kebangsaan Malaysia, Malaysia throughout the experimental duration. It was characterized by conducting water quality analysis (methods detailed in section 2.4).

2.2 Collection and preparation of coagulant

The seeds of *Bauhinia purpurea* and *Leucaena leucocephala* were collected from wild plants by the roadside near Universiti Kebangsaan Malaysia. The preparations involved no chemicals to minimize the toxicological effect while promoting sustainability. The seeds were separated individually from the outer skin through manual selection; then cleaned using distilled water to remove any remaining foreign bodies. Afterward, the seeds were dried in a dryer (BS 100, Protech, Malaysia) at 40°C for 2 days. Both dried samples of the two different species were ground separately using a commercial blender (Panasonic MX-GM1011, Malaysia) into powders. To ensure uniform particle size, respective powders were filtered using a sieve of Ø1mm. Filtered samples were stored in their individual vacuum-sealed containers until further use.

The coagulant stock was prepared by mixing 1 g of respective powder into 1 L of distilled water for 45 minutes, to obtain a 1 g/L stock solution. The solution was then filtered using a vacuum pump (GAST Manufacturing, USA) method to separate the supernatant and the powder residue. The supernatant was then collected to be used as coagulant stock solution, which needs to be prepared freshly before every usage.

2.3 Coagulation test (Jar test)

The coagulation treatment was performed through the jar test method using a six paddle flocculator (JLTP, VELP Scientifica, Europe). 500 mL beakers were used to contain a 400 mL total solution of coagulant stock and wastewater, mixed at different ratios to achieve specified dosages using equation (1). Selected coagulant dosages for this research work were 0.03, 0.04, 0.05 and 0.06 mg/L, for each type of coagulant.

$$M_1 v_1 = M_2 v_2 \quad (1)$$

Where M_1 is concentration of coagulant stock (g/L), v_1 is volume of coagulant stock (mL), M_2 is specified treatment dosage (g/L), and v_2 is treatment working volume (mL).

The rapid and slow mixing speeds for the treatment were set at 150 rpm (2 minutes) and 40 rpm (20 minutes), respectively, followed by a sedimentation process for 24 hours. The supernatant was collected from the upper layer of the treated wastewater using a pipette for further analysis. The concentration of TSS of treated wastewater was compared to its initial characteristics to determine the efficiency of each species as a coagulant for coffee processing wastewater.

2.4 Water quality analysis

The characteristics of wastewater were determined in terms of COD, pH, and TSS. HACH methods were used to analyse parameters of COD (catalogue number 8000) and TSS (catalogue number 8006) using a spectrophotometer DR6000 (HACH, USA). While parameter of pH were read by immersing probe of pH meter (pH HQ11d, HACH, USA) individual samples until stable reading recorded by the instrument. For the treated wastewater, TSS was considered as main observation; and analysed using the same approach as characterization.

3. Results and discussion

3.1 Characteristics of wastewater

Coffee processing effluent was characterised as an acidic wastewater with a pH of 3.97, with COD and TSS concentration of 8 470 mg/L and 630 mg/L, respectively. This high organic load wastewater poses a dangerous threat to waterways and ecosystems. The aerobic decomposition process of this organic loads by locally existing microbes consuming dissolved oxygen in water, leads to oxygen depletion (Arthur et al., 2023). Sediments existing in the waterway may act as an oxygen sink, drawing down the oxygen level which leads to hypoxic or even anoxic conditions, disrupting aquatic biodiversity (Sun et al., 2024). Excess organic matter also leads to algal bloom, which causes eutrophication, further depleting oxygen and hindering light penetration (Altieri et al., 2019). High pollution also leads to alteration of microbial communities, increasing pathogenicity and antibiotic resistance (Ahmad et al., 2024).

Therefore, proper wastewater treatment is crucial to mitigate these adverse environmental effects. Without adequate treatment, the continuous discharge of untreated or poorly treated effluent into natural waterways can overwhelm the ecosystem's self-purification capacity (Maddah, 2022). Treatment processes are essential to significantly reduce the organic load, neutralize acidity, and remove suspended solids before discharge. In regions where coffee production is economically significant, implementing cost-effective and sustainable wastewater treatment technologies is imperative to balance industrial activity with environmental protection (Said et al., 2023).

3.2 Performance of coagulation treatment for total suspended solid (TSS) removal

The concentration of TSS was selected as the primary parameter of observation in this study, as the coagulation treatment primarily targeted the removal of suspended solids. As shown in figure 1, the coagulant derived from *Leucaena leucocephala* (noted as 'LL' in the graph) exhibited the highest removal efficiency of 49% at a dosage of 0.04 g/L, which was comparable to *Bauhinia purpurea* (noted as 'BP' in the graph), achieving 50% removal at a higher dosage of 0.06 g/L. This suggests that LL requires a lower dosage to achieve similar performance, indicating more efficient resource usage.

In terms of removal trends, *Leucaena leucocephala* showed increased efficiency from 0.03 g/L to 0.04 g/L, followed by a decline in performance at higher dosages, reaching a minimum removal efficiency of 27%. This decrease at elevated dosages could be attributed to charge reversal and re-stabilisation of particles, which has been widely reported when excess coagulant disrupts optimal floc formation (López-Maldonado et al., 2014; Zhou et al., 2024). This indicates that the optimum dosage for *Leucaena leucocephala* in treating this specific wastewater was 0.04 g/L. Conversely, the removal efficiency for *Bauhinia purpurea* continued to improve with increasing dosage, suggesting that its optimum condition lies at 0.06 g/L or potentially higher. This gradual improvement could be linked to the availability of additional binding sites and active compounds

within BP that effectively captured suspended solids across a wider dosage range, as similarly observed in studies on *Moringa oleifera* and other plant-based coagulants (Garde et al., 2017). However, it is important to note that higher dosages correspond to greater resource consumption which should be considered in large-scale applications. This treatment does not cause significant pH variation to the treated effluent, showing no significant change in the content of H^+ ion during the treatment (figure 2). This stability in pH could be beneficial for subsequent secondary treatment processes, particularly those that favour an acidic environment for enhanced efficiency (Yin, 2010).

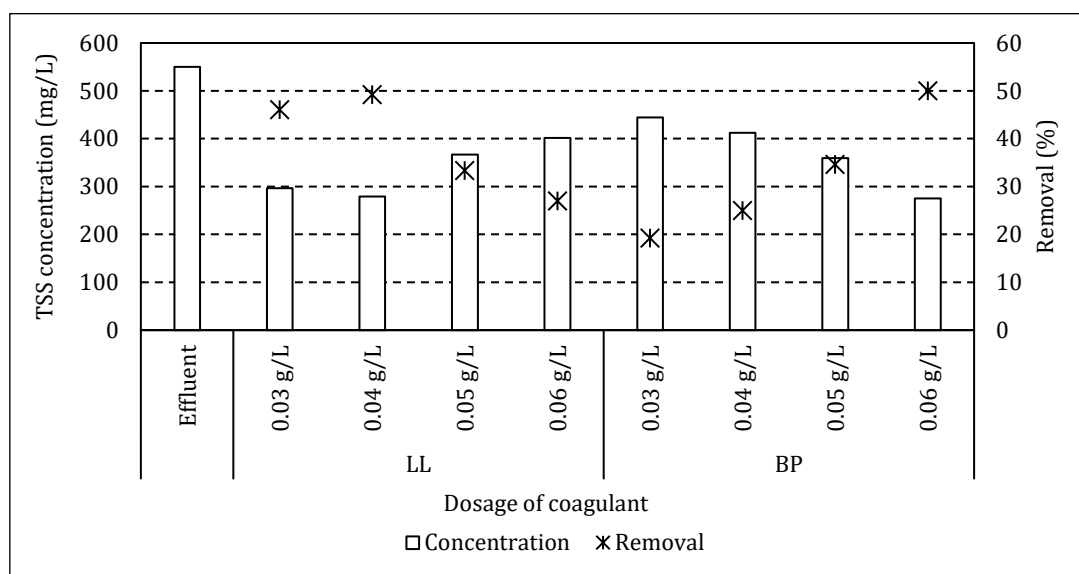


Figure 1. TSS concentration after coagulation-flocculation treatment.

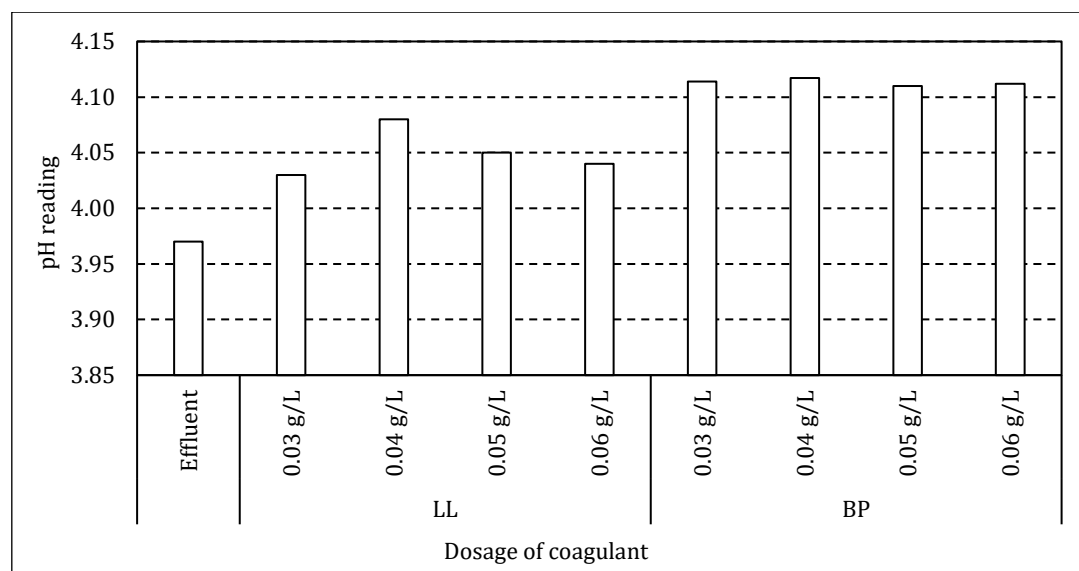


Figure 2. Variation of pH after coagulation-flocculation treatment.

4. Conclusion

Comparing seeds of both *Leucaena leucocephala* and *Bauhinia purpurea* as chemically-free prepared natural coagulants in treating wastewater with high organic loads, *Leucaena leucocephala* showed better efficiency at lower dosage required. With low dosage of 0.04 g/L, it was able to achieve the highest TSS removal at 49%, compared to *Bauhinia purpurea* achieving 50% removal at highest 0.06 g/L dosage. The treatment also does not show significant alteration to the final pH of the treated effluents. As coagulant used was environmentally friendly, sludges produce possess good opportunity for resource reclamation.

These findings highlight the potential of *Leucaena leucocephala* seed extract as an alternative to chemical coagulants, offering cost-effective and eco-friendly treatment that can be adopted in decentralized or small-scale wastewater treatment systems. Wider application could reduce reliance on conventional coagulants that generate hazardous by-products. Future research should evaluate the performance of these coagulants with different types of wastewaters, explore scale-up feasibility and investigate the physicochemical properties of the sludge for resource recovery applications such as composting or soil amendment.

Acknowledgements

The authors would like to express their sincere gratitude to Universiti Kebangsaan Malaysia (UKM) for providing the necessary facilities and support throughout this study. This research was supported by grants GP-K023472.

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