

REVIEW ARTICLE

Sustainable Water Purification Using Plant-Derived Bio coagulants: A Case Study on Moringa Oleifera

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Abstract. The rising cost, health concerns, and environmental implications associated with conventional chemical coagulants such as alum and ferric chloride have intensified the search for sustainable, biodegradable, and locally available alternatives for water and wastewater treatment. In this context, Moringa oleifera seeds have emerged as a promising natural coagulant due to the presence of water-soluble, positively charged (cationic) proteins that effectively bind and neutralize negatively charged colloidal particles. This study investigates the coagulation performance of Moringa oleifera seed powder for turbidity reduction in synthetic wastewater through a series of controlled jar-test experiments. Coagulant dosages ranging from 0 to 150 mg/L were evaluated to determine their influence on turbidity removal efficiency and coagulation behavior. The results revealed a clear improvement in water clarity with increasing dosage up to a critical point, beyond which overdosing led to marginal performance decline due to charge reversal and particle restabilization. The optimum dosage was identified as 100 mg/L, achieving a maximum turbidity removal efficiency of 81.66%. These findings highlight the significant potential of Moringa oleifera as a low-cost, eco-friendly, and sustainable alternative to chemical coagulants, particularly for application in rural or resource-limited water treatment systems. The biodegradability and minimal sludge toxicity offer significant environmental advantages over synthetic coagulants. The study also reaffirms the role of plant-based materials in promoting decentralized and community-scale water treatment solutions. Moringa oleifera demonstrates strong applicability for developing countries seeking affordable, efficient, and nature-based treatment technologies.

Keywords: Moringa oleifera, natural coagulant, wastewater treatment, turbidity reduction, jar test, sustainable materials, coagulation–flocculation

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1. Introduction

Emerging Coagulation–flocculation remains one of the most important physicochemical processes used in water and wastewater treatment, particularly for removing colloids, suspended solids, and turbidity that cannot be settled by gravity alone [1]. While conventional coagulants such as alum, ferric chloride, and polyaluminum chloride are widely used for their proven efficiency [2], increasing attention has been directed toward their long-term environmental, operational, and health-related drawbacks. Overdosing or prolonged exposure to these chemicals may lead to elevated residual metal concentrations, potential neurological risks, increased sludge generation, and undesirable pH alterations, as noted by Smith et al. [3] and other researchers.

Given these concerns, the search for sustainable, biodegradable, and low-cost coagulant alternatives has intensified, particularly in regions with limited access to chemical supplies [4]. Natural coagulants, especially plant-derived materials, are increasingly recognized for their environmental compatibility, local availability, and reduced toxicity [5]. *Moringa oleifera*, commonly known as the drumstick tree, has emerged as one of the most promising natural coagulants due to the presence of water-soluble, positively charged proteins that neutralize negatively charged colloidal particles, thus enhancing floc formation (Ndabigengesere & Narasiah) [6].

In line with this research direction, the present study aims to evaluate the effectiveness of *Moringa oleifera* seed powder as a natural coagulant for turbidity reduction, to identify the optimum dosage capable of achieving maximum treatment efficiency, and to compare influent and effluent turbidity levels using a standard jar-test procedure. As highlighted in earlier works by Jahn and Olson [7] & Muyibi [8], the use of *Moringa oleifera* offers a sustainable and community-friendly approach suitable for both rural and decentralized treatment systems. By examining its

coagulation performance in controlled laboratory conditions, this study contributes to the growing body of evidence supporting natural coagulants as viable alternatives to conventional treatment chemicals [9].

2. Literature Background

The use of natural coagulants for water and wastewater treatment has been extensively studied over the past three decades, especially as researchers began recognizing the environmental and economic limitations of synthetic chemicals. Early foundational work by Jahn established that *Moringa oleifera* seeds contain active cationic proteins capable of destabilizing colloidal suspensions through adsorption and charge neutralization, functioning in a manner comparable to synthetic polyelectrolytes [10]. This discovery sparked extensive global interest, especially in regions facing financial and logistical barriers to procuring conventional coagulants.

Later studies by Ndabigengesere & Narasiah further validated these findings by demonstrating that *Moringa oleifera* can achieve turbidity reductions comparable to alum, especially in medium- to high-turbidity waters [6]. Their research also emphasized that the sludge generated from *Moringa* treatment is biodegradable and environmentally benign, offering a significant advantage over metal-based coagulants. Subsequent investigations expanded the application of *Moringa* to various water qualities, including river water, groundwater, textile effluents, and municipal wastewater.

Beyond coagulation performance, Muyibi & Evison examined the plant's additional benefits, including antimicrobial properties and the capacity to soften hard water through interactions with divalent ions [11]. More recent studies have evaluated modified *Moringa* extracts—such as salt-extracted proteins, purified cationic fractions, and defatted seed powder—to enhance solubility and coagulation efficiency (Okuda et al.) [12]. These modifications aimed to improve performance in low-turbidity waters, where

traditional Moringa powder shows reduced effectiveness.

Comparative studies between natural and synthetic coagulants have consistently highlighted the safety and sustainability advantages of Moringa oleifera. According to Kumar & Abraham [13], natural coagulants significantly reduce risks of toxic residuals, require lower energy for processing, and support decentralized treatment systems. However, some authors note limitations such as potential organic loading, shorter shelf life, and reduced performance in certain water matrices. Despite these minor drawbacks, the overall body of literature strongly supports Moringa oleifera as a promising, eco-friendly coagulant suitable for low-cost community water treatment systems, particularly in resource-limited settings [14].

3. Materials and Methods

3.1. Wastewater Sample

For the purpose of this experimental study, a synthetic wastewater sample was prepared to ensure uniformity and reproducibility across all trials. Synthetic wastewater was selected instead of actual municipal wastewater to eliminate variability caused by fluctuating environmental and operational conditions. The wastewater matrix was formulated by dispersing fine clay particles in distilled water until an initial turbidity of 120 NTU was consistently achieved. This turbidity level represents moderately polluted water and is commonly used in coagulation–flocculation studies to evaluate coagulant performance under controlled laboratory conditions. The sample was thoroughly mixed prior to each experimental run to maintain homogeneity and avoid settling of suspended particles.

3.2. Preparation of Coagulant

The natural coagulant used in this study was derived from Moringa oleifera seeds. Mature and fully dried seed pods were collected, and the seeds were manually removed from the shells. To ensure

optimal protein activity, the seeds were first sun-dried for several hours to eliminate residual moisture that could interfere with powder preparation or storage. The dried kernels were then ground into a fine powder using a high-speed laboratory grinder. To achieve uniform particle size distribution and enhance solubility during mixing, the powdered material was passed through a 600-micron mesh sieve. The resulting fine, light-colored powder served as the active coagulant and was stored in airtight containers to prevent moisture absorption prior to use in jar tests.

3.3. Jar Test Procedure

A conventional jar-test apparatus was employed to evaluate the coagulation efficiency of Moringa oleifera seed powder. The jar test is a standard method used to simulate rapid and slow mixing stages in water treatment plants and allows assessment of floc formation under controlled hydrodynamic conditions.

The study examined seven different dosages of Moringa oleifera powder: 0, 25, 50, 75, 100, 125, and 150 mg/L. This range was selected to identify both the minimum effective dose and the point at which overdosing might result in re-stabilization of particles.

3.3.1. Jar Test Steps

1. Addition of Coagulant:

The predetermined quantity of Moringa oleifera powder was added to 1-liter beakers containing the synthetic wastewater. Each dosage was tested in separate beakers to allow direct comparison.

2. Rapid Mixing (Coagulation Stage):

Immediately after addition, the samples were subjected to rapid mixing at 200 rpm for 2 minutes. This step ensures thorough dispersion of the coagulant and promotes initial destabilization of colloidal particles.

3. Slow Mixing (Flocculation Stage):

Following rapid mixing, the speed was reduced to 40 rpm, and the samples were mixed gently for 15 minutes. This stage facilitates the collision and aggregation of destabilized particles,

leading to the formation of larger, denser flocs capable of settling.

4. Settling Period:

After the mixing stages were completed, the samples were allowed to settle undisturbed for 30 minutes. During this period, flocs descended to the bottom of the beakers, resulting in visibly clearer supernatant.

5. Turbidity Measurement:

After settling, the supernatant from each beaker was carefully extracted without disturbing the settled flocs. The remaining turbidity was measured using a calibrated nephelometer, and the turbidity reduction efficiency was calculated by comparing influent and effluent values.



Fig. 1. Jar-Test setup

The Figure 1 shows a typical laboratory jar-test setup, commonly used in water and wastewater treatment research. This setup helps evaluate how well *Moringa oleifera* powder works as a natural coagulant to reduce turbidity.

4. Results and Discussion

The results clearly demonstrate that *Moringa oleifera* seed powder exhibits significant coagulation potential, with turbidity decreasing progressively as the dosage increases from 0 mg/L to 100 mg/L. At lower concentrations, particularly 25 mg/L and 50 mg/L, a substantial reduction in turbidity is observed, indicating that even small doses of the natural coagulant can effectively destabilize suspended particles.

Table 1. Dosage Vs Removal Efficiency

Dosage (mg/L)	Final Turbidity (NTU)	Removal Efficiency (%)
0	120	0.00
25	72	40.00
50	45	62.50
75	28	76.67
100	22	81.67
125	25	79.17
150	30	75.00

The removal efficiency increases sharply within this range, rising from 40.00% at 25 mg/L to 62.50% at 50 mg/L, suggesting that the active cationic proteins in the seed powder are effectively neutralizing negatively charged colloids.

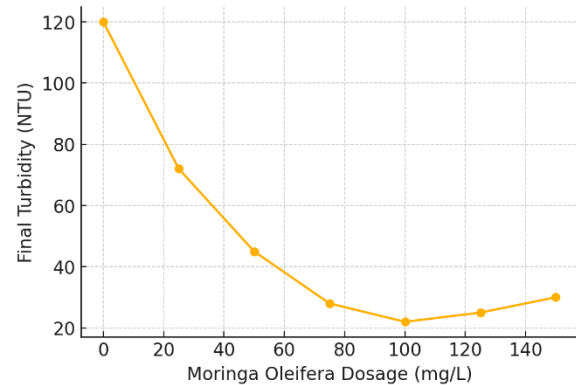


Fig. 1. Turbidity reduction curve

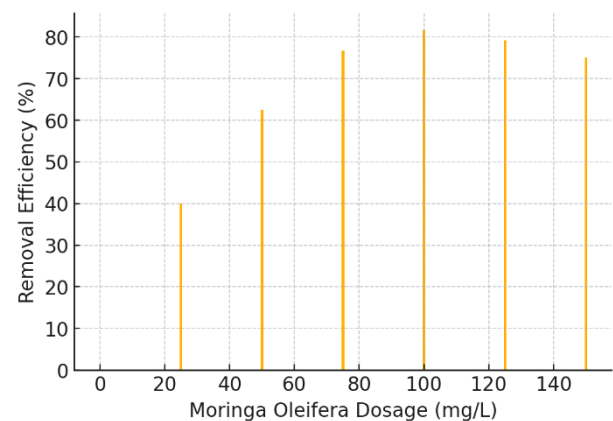


Fig. 2. Turbidity removal efficiency

As the dosage increases to 75 mg/L and 100 mg/L, turbidity removal reaches its optimal performance, with efficiencies of 76.67% and 81.67% respectively. This peak performance at 100 mg/L indicates that this dosage provides the most effective balance between particle destabilization and floc formation. The formation

of dense, settleable flocs at this concentration aligns with the expected behavior of natural coagulants, where sufficient protein availability enhances aggregation efficiency.

However, further increases in dosage beyond the optimal point lead to a slight decline in removal efficiency. At 125 mg/L, turbidity increases slightly to 25 NTU (79.17% efficiency), and at 150 mg/L, turbidity further rises to 30 NTU (75.00% efficiency). This decline is attributed to charge reversal or particle restabilization, a phenomenon well-documented in coagulation studies. When excessive coagulant is added, the additional positively charged proteins may over-neutralize the system, reversing the surface charge of particles and reducing floc stability. This leads to the formation of smaller or weaker flocs that remain suspended rather than settling.

Overall, the results highlight the importance of determining and maintaining an optimum coagulant dosage. In this study, 100 mg/L is identified as the most effective dosage, achieving the highest turbidity removal while avoiding the negative effects associated with overdosing. These findings align with previous literature indicating that natural coagulants exhibit a dosage-dependent performance curve, where both underdosing and overdosing can reduce treatment efficiency.

5. Conclusion

The findings of this study clearly demonstrate the significant potential of *Moringa oleifera* seed powder as a natural, cost-effective, and environmentally sustainable coagulant for turbidity removal in wastewater treatment. Through controlled jar-test experiments, *Moringa* powder exhibited strong coagulation properties across a range of dosages, with a notable improvement in water clarity as dosage increased. The optimum performance was achieved at a dosage of 100 mg/L, resulting in a turbidity reduction efficiency exceeding 80%, which is

comparable to the performance levels typically associated with conventional chemical coagulants.

The effectiveness of *Moringa oleifera* can be attributed to the presence of water-soluble cationic proteins that facilitate charge neutralization and floc formation, enabling the rapid settling of suspended and colloidal particles. Beyond its technical performance, *Moringa* also offers distinct advantages such as biodegradability, low toxicity, local availability, and minimal environmental impact. These characteristics make it particularly suitable for application in rural or resource-limited regions, where access to traditional treatment chemicals may be limited or economically unfeasible.

The use of plant-based coagulants aligns with global sustainability goals by reducing reliance on synthetic chemicals, lowering sludge toxicity, and promoting the use of renewable natural resources. While the study focused on turbidity removal using synthetic wastewater, the results provide a strong foundation for future research involving real wastewater samples, additional water quality parameters, and pilot-scale applications.

The outcomes of this study reinforce the viability of *Moringa oleifera* as a promising natural coagulant that can contribute to improving water quality in an affordable, sustainable, and environmentally conscious manner. Its adoption has the potential to support decentralized treatment systems, empower local communities, and address water purification challenges in developing regions.

6. Future Scope

Future studies can broaden the applicability of *Moringa oleifera* by evaluating its performance on additional water quality parameters such as COD, BOD, TSS, and color. Testing on real municipal wastewater will provide insights into its effectiveness under practical field conditions. Comparative analyses with alum and other natural coagulants can help establish its relative efficiency and operational advantages. Furthermore, scaling the process to pilot-plant or community-level

systems will support the development of sustainable, low-cost water treatment solutions for wider use.

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