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Potential of Sustainable Green Coagulants Extracted from Plant Leaves for Turbidity Removal from Water

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ABSTRACT
Coagulation–flocculation is considered one of the most effective methods for reducing turbidity in water. This study evaluates the efficiency of six plant-based green coagulants, including *Myrtus communis*, *Laurus nobilis*, *Eucalyptus camaldulensis*, *Olea europaea*, *Punica granatum*, and *Citrus limon*, for the removal of turbidity from kaolin-simulated water under different pH conditions. The plant leaves were dried, ground, and extracted using distilled water to prepare the coagulant solutions. Jar test experiments were conducted using five coagulant concentrations (500, 1000, 3000, 5000, and 7000 mg/L) at pH levels of 5, 7, and 8. The coagulation process included rapid mixing at 180 rpm for 5 min, slow mixing at 50 rpm for 15 min, followed by 30 min settling time. Turbidity removal efficiency was calculated based on initial and final turbidity values measured in NTU. The results demonstrated that the efficiency of turbidity removal varied according to plant type, concentration, and pH. The best removal results were achieved using a green coagulant at a concentration of 1000 mg/L of *Myrtus communis* (73%) at pH 7, *Punica granatum* at a concentration of 500mg/L (74%) at pH 8, *Laurus nobilis* at a concentration of 500 mg/L (69%) at pH 8 and Citrus limon at a concentration of 1000 mg/L (65%) at pH 8. While the plants *Eucalyptus* and *Olea europaea* at a concentration of 500 and 3000 mg/L of green coagulant removed 66% and 62% of turbidity, respectively. The idea of a sustainable environment with natural green coagulants found in the ecosystem is supported by these findings.

INTRODUCTION

As the population grows, so does the need for clean water **(Kristianto, 2017)**, Water still includes high levels of pollutants such organic compounds, heavy metals, and dangerous bacteria, coming from sources like rivers, lakes among others **(Fitriani *et al*., 2020)**. The characteristics of raw water are also impacted by wastewater entering water bodies **(Imron *et al*., 2019)**. The direct consumption of raw water by humans will be detrimental to their health. To lower the pollutant level, raw water and wastewater before it is consumed, it must be appropriately treated **(Mohamad *et al*., 2021; Said *et al*., 2021)**. Traditional and advanced technologies were used to convert raw water and wastewater into clean water. These techniques are highly efficient in processing results

(Ang *et al*., 2020; Kurniawan *et al*., 2020). Coagulation and flocculation are part of water, wastewater and primary treatment units that remove suspended particles **(Abu Bakar *et al*., 2021)**. In coagulation and flocculation processes, the type of coagulants and coagulants is crucial in the processing procedure **(Ahmad *et al*., 2021b)**.

In order to prevent flocculation formation in unstable conditions, the theory of coagulation and flocculation involves destabilizing suspended particles by adding coagulants and dispersants to lessen the repulsive forces between them **(Fard *et al*., 2021)**. Following their collision, the unstable particles create larger flocculation that are simpler to deposit **(Aktas *et al*., 2013)**. While chemical coagulants are highly effective, their environmental and health drawbacks have shifted research attention toward eco-friendly plant-based alternatives. Although previous studies, such as **Salem *et al.* (2023)** and **Ahmad *et al.* (2022)**, evaluated specific natural coagulants and agricultural wastes for turbidity removal, a clear research gap remains regarding the comparative efficacy of diverse local Iraqi flora. Specifically, among the six local plants investigated in this study (*Citrus limon*, *Punica granatum*, *Olea europaea*, *Eucalyptus*, *Myrtus communis*, and *Laurus nobilis*), the application of *Myrtus communis* and *Laurus nobilis* as sustainable green coagulants has not been previously explored or contrasted in a single comparative matrix. Therefore, this study introduces a novel, comprehensive comparative evaluation of these six local Iraqi plant materials, establishing their individual performance, optimal operational conditions, and relative efficiencies in turbidity removal to provide a highly sustainable, eco-friendly, and decentralized water treatment strategy. Derivatives of alum recovered from solid waste has been successfully utilized in water and wastewater treatment, indicating that a measure of the recovered coagulant source should be investigated in addition to the conventional commercial source (**Mohamed *et al*., 2019**).

Since industrial wastewater releases harmful substances into surface waters, therefore it is recognized as one of the most frequent sources of water pollution **(Taha *et al*., 2022)**. However, the enormous amounts of organic matter in wastewater from the food industry cause water contamination, odor production, algal blooms, and the obstruction of aquatic life. Since pollutants have a detrimental effect on both the ecosystem and human health, treatment must be centered on eliminating or minimizing them. Physical techniques like sedimentation, filtration, and adsorption; chemical techniques like coagulation, oxidation, and electrochemical processes; and biological techniques like phytoremediation and the use of microorganisms as bioreactors can all be used to treat wastewater conventionally **(Fadhil & AI-Baldawi, 2010)**. In wastewater primary treatment, coagulation and flocculants (CF) is a physical and chemical treatment technique that helps remove suspended materials. Green coagulants may offer a more sustainable alternative to conventional chemical coagulants due to their biodegradable nature and renewable sources. However, claims regarding their complete safety or the absence of harmful residues should be interpreted cautiously unless parameters such as sludge toxicity, residual organic carbon, and treated-water quality are thoroughly evaluated. Previous studies have reported promising environmental benefits of plant-based coagulants, but further assessment is still required to confirm their long-term safety and environmental impact **(Daud *et al*., 2023)**. Natural treatment materials such as chitosan hydrogel nanocomposites have been shown to decrease nutrient and microbial concentrations in aquaculture effluents, so several water-quality parameters should be considered when assessing these materials. (**Kelany *et al*., 2024**).

By lowering the pressures needed to separate suspended particles from colloidal materials, coagulation works. Agglomerates are created when the particles group together and settle readily. Colors, organic chemicals, heavy metals, oils, and fats are all treated with physical and chemical methods such as flocculation and coagulation on a variety of industrial wastewaters **(Daud *et al*., 2023)**. Common substances like alum, ferric chloride, ferric sulfate, polyaluminum chloride, and synthetic organic polymers are employed in the traditional coagulation and flocculation process **(Oladoja, 2015)**. Since they are affordable, environmentally friendly, and do not leave any harmful residues behind, green coagulants provide modest residential complex treatment facilities in middle-income nations like Iraq an alternative sustainable option. In this study, six plants were compared to kaolin removal as a novel and promising green coagulant for wastewater treatment. The chosen plants are found all year round in Iraq and are widely distributed. Studies employing green industrial coagulants are crucial since they promote more naturally occurring effluent treatments, which is crucial given the startling rise in weather-related and environmental disasters. Green coagulant is environmentally sustainable, biodegradable, safe, and produces less sludge **(Salem *et al*., 2023)**.

MATERIALS AND METHODS

1. Plant Selection and Coagulant Powder

Six plants were chosen to determine whether they can be used as green coagulants. Table (1) consists of 6 selected local plants of *Myrtus communis, Laurus nobilis, Eucalyptus camaldulensis, Olea europaea, Punica granatum* and *Citrus limon.* The plant leaves were first gathered, cleaned with distilled water (approximately 2 L for each 100 g of leaves), and then put in an oven for two days at 70 °C, with a final moisture constant below 10%. For use in coagulant water extraction, the dried leaves were pulverized and sieved to create a fine powder with a concentration of 38 μm. The samples were grounded using an electric laboratory grinder. The prepared powders were stored in airtight glass containers at room temperature and used within two weeks to avoid moisture absorption and degradation of active compounds. The same pretreatment conditions were applied identically to all investigated plant species **(Ahmad *et al*., 2022)**. A basic solution of 500–7,000 mg/L of coagulants was made by aqueous extraction, which involved combining 10 g of plant powder with 100 ml of distilled water for 30 minutes **(Kumar *et al*., 2021)**. After passing through 0.33 mm Belgian Zylba paper, the coagulant extract was placed in a Duran container for storage. The filtrate was used directly in the experiments, while the residue was discarded. Therefore, the extraction yield was not calculated since the extract was used in its liquid form. All of these coagulant extraction procedures were completed at the same time.

2.Water with Kaolin Preparation

The plant was tested as a green coagulant by creating fake turbid water by combining water and kaolin powder. In order to mimic an initial turbid concentration of 500 ± 50 NTU, a 500 NTU concentration of industrial turbid water was prepared by combining 1.5 g of kaolin with 3 liters of distilled water in a flask and stirring the mixture for 30 minutes to make it homogenous. Turbidity measurements were performed in triplicate, and the results were expressed as mean ± standard deviation (SD) **(Xue *et al*., 2019; Ahmad *et al*., 2022)**.

3. Procedure for Testing Green Coagulant Removal Efficiency

The experiment was run with six 1000 ml beakers, each containing 500 ml of artificial water and coagulant. These six beakers were filled with coagulant at various concentrations (500, 1000, 3000, 5000, and 7000 mg/L). A control sample consisting of kaolin suspension, without the addition of any coagulant, was prepared and analyzed under the same experimental conditions for comparison purposes. Five minutes of high mixing speed (180 rpm) and fifteen minutes of medium mixing speed (50 rpm) were used in the experiment. Following the coagulation and flocculation procedure, the samples were allowed to settle in the beakers for half an hour. Each beaker's water was sampled, and a turbidimeter was used to measure the turbidity. To guarantee dependability and minimize variances in readings and average values, the sampling process was carried out three times. The turbidity removal efficiency was computed using equation (1) **(Khouni *et al.*, 2020)**.

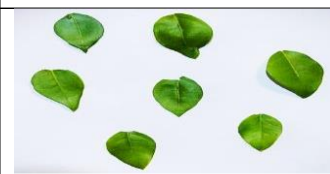
$$\text{Removal efficiency (\%)} = \frac{Ti - Tf}{Ti} \times 100 \qquad \dots (1)$$

Where:

Ti = Initial turbidity (NTU);

Tf = Final turbidity (NTU).

Table 1. Plants and leaves selection for green coagulants.

Scientific name	*Common name*	*Collection site*	*Plant shape*	*Part used*
Citrus limon	Lemon	grove		
Eucalyptus camaldulensis	Eucalyptus	A farm in Al-Zubair district		
Laurus nobilis	Bay leaf	Not specified (commercially obtained sample)		
Myrtus communis	Myrtle	Home garden		
Punica granatum	Pomegranate	A farm in Al-Zubair district		
Olea europaea	Olive	A farm in Al-Zubair district		

4.Statistical Analysis for Turbidity Removal Efficiency

SPSS version 21 (IBM, USA) was used to statistically examine the green coagulant's effectiveness in removing turbidity. A significant deviation from the experimental data is indicated by a 95% confidence interval ($p < 0.05$). Using Tukey HSD test, a three-way analysis of variance (ANOVA) was conducted to ascertain the impact of varying green coagulant masses on turbidity reduction (**Mohamad *et al*.,**

2021). The response variable was the turbidity removal efficiency (%) tested in triplicate (n = 3). Data normality and homogeneity of variances were verified using Shapiro-Wilk and Levene's tests, respectively. To ensure statistical assumptions were met, percentage data underwent an arcsine transformation prior to ANOVA. Significant differences were determined using Tukey's HSD test ($p < 0.05$).

5.Adjusted pH

The initial pH was adjusted to acidic (pH 4 using 0.1 M HCl), normal (pH 7), and alkaline (pH 8 using 0.1 M NaOH) using a calibrated pH meter. The final pH after coagulation was not measured, since the study strictly focused on evaluating the turbidity removal efficiency within these specific initial pH environments.

RESULTS AND DISCUSSION

Turbidity Removal Efficiency with Sustainable Coagulant

The six local plant were tested with the green coagulant extraction to remove turbidity. The turbidity removal of the selected plants as coagulants are shown in Figs. (1-6). According to the findings, the effectiveness of turbidity removal through the use of plant extracts varies depending on the pH. It was observed that pH 7 and pH 8 gave the highest removal rates in comparison with pH 5, which indicates that conditions that are neutral or mildly alkaline improve the effectiveness of plant materials that are used as coagulants. The greatest clearance rate at pH 7 was 73% for *Myrtus communis* at a concentration of 1000mg/l, 62% for *Olea Europaea* at 3000 mg/L and 57% for *Laurus Nobilis*. Optimizing the dosage and conditions of treatments would help decrease turbidity and algal load in water bodies using plant-derived coagulants, thus reinforcing the argument for using locally available botanical materials for clarification treatment. (**Abouzied *et al.*, 2023**)

The highest removal efficiency was 74% at 500 mg/L for *Punica granatum* at pH 8, followed by 67% at 7000mg/L for *Myrtus communis*, and 69% at 500mg/L for *Laurus nobilis*. At pH 5, *Olea Europaea* and *Punica Granatum* are both 56% at 500 mg/L, whereas *Myrtus communis* is 65% higher at 1000%. *Myrtus communis* showed high efficiency and relatively constant performance across all pH values, which may indicate the stability of its active components under all different conditions. As for *Punica granatum*, we noted that it recorded the highest efficiency at pH 8 due to its active compounds operating in a slightly alkaline medium. *Eucalyptus* performance was relatively lower, with its highest removal percentage not exceeding 66% at pH 8 and a concentration of 3000%. We also noted that *Citrus Limon* performance was lower compared to the plants above, which may be due to its effect on pH or the lack of active ingredients. Using *punica granatum* coagulant at 1000 mg/L and a pH of 7 resulted in the maximum turbidity reduction rate of 44%, as shown in Fig. (1). However, when the concentration rose to 3000 mg/L, the clearance rate dropped to 27%, indicating that the dose had an impact on the coagulant's effectiveness. The higher charge on the coagulant molecules, which stabilizes the suspended particles and stops their aggregation and sedimentation, explains the decreased efficiency at high concentrations (3000 mg/L). However, there are enough binding sites to improve flocculation and turbidity removal at the ideal concentration (1000 mg/L).

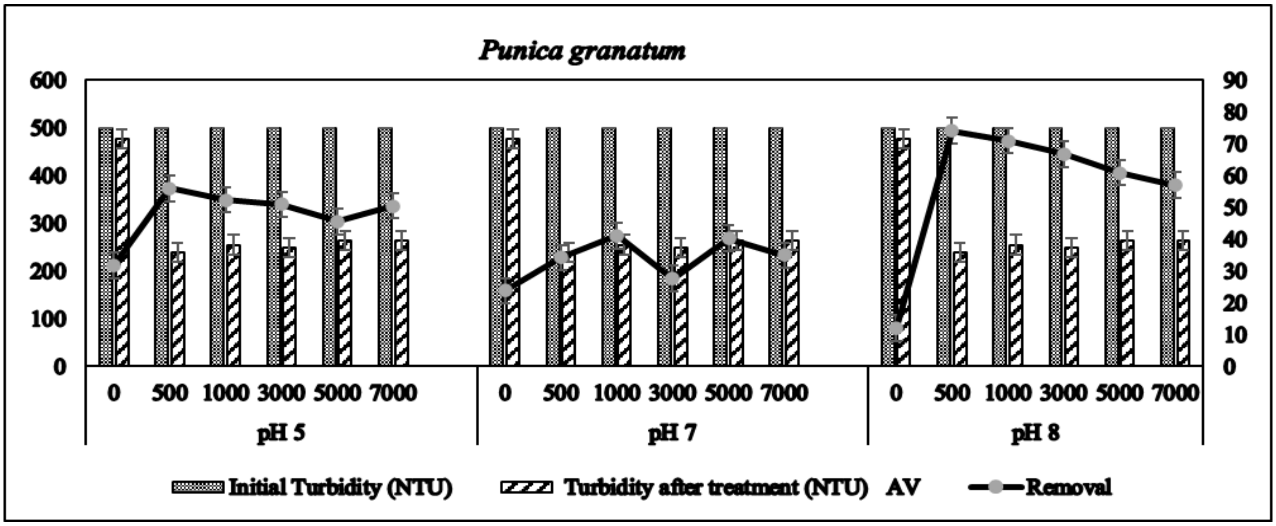


Fig. 1. Turbidity removal efficiency (%) of *Punica granatum* at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate measurements (n = 3), and error bars indicate the standard deviation.

The maximum turbidity reduction rate, as demonstrated in Fig. (1), was 56% when 500 mg/L of *punica granatum* coagulant was used at a pH 5. Additionally, the results demonstrated high clearance rates at 1000 and 3000 mg/L (52% and 51%, respectively), however the efficiency dropped to 45% at 5000 mg/L and then marginally increased to 50% at 7000 mg/L. At pH 8, *Punica granatum* coagulant attained a high turbidity removal effectiveness of 74% at a concentration of 500 mg/L, as illustrated in Fig. (1). The efficiency progressively dropped to 70% and 66%, respectively, as the dose was increased to 1000 and 3000 mg/L. Removal decreased to 60% and 57% when the concentration increased further to 5000 and 7000 mg/L. The observed decrease in turbidity removal efficiency at higher coagulant doses is hypothesized to be a result of overdosing, which potentially leads to particle restabilization. In this proposed mechanism, an excess of coagulant polymers or proteins may fully cover the Kaolin particle surfaces, causing charge reversal or steric hindrance that prevents effective bridging and flocs formation. While specific surface charge measurements, such as zeta potential and particle size analysis, were not performed in this study, this restabilization hypothesis aligns with well-established coagulation theories reported in similar green coagulant literature. According to these findings, *Punica granatum* powder's active compounds were more effective at removing suspended matter at a basic pH of 8 than at higher doses.

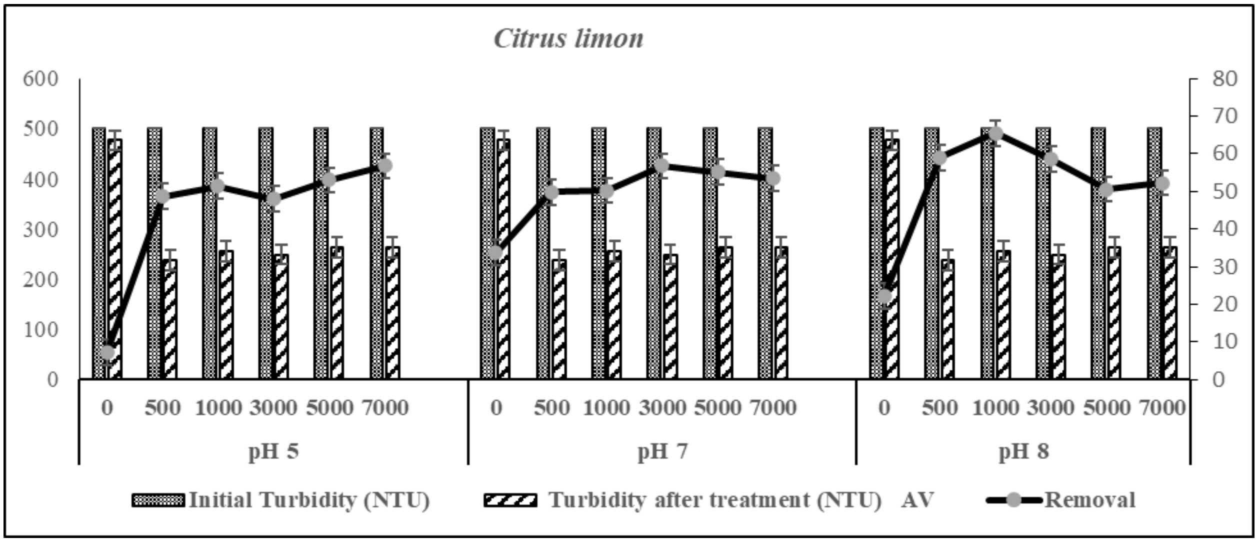


Fig. 2. Turbidity removal efficiency (%) of (*Citrus limon*) at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate 1measurements (n = 3), and error bars indicate the standard deviation.

Extracts from *Citrus limon* leaves are known to contain acidic components, such as citric acid, which can inherently alter the pH of the aqueous medium upon addition. This potential shift in pH is a critical factor in interpreting turbidity removal, as it influences particle charge and coagulant solubility. To mitigate this confounding effect and isolate the performance of the coagulant, the initial pH was strictly controlled at specific baseline values (5, 7, and 8) using buffer-like adjustments prior to the coagulation process. At a concentration of 3000 mg/L, the maximum turbidity removal rate was 56%, while at 1000 mg/L, the lowest value was 49%, as shown in Fig. (2). Similar outcomes were obtained with the remaining doses (50-55%). The removal rates at the remaining concentrations (500, 5000, and 7000 mg/L) were found to be rather close, falling between 50% and 55%. This suggests that there was no discernible impact on removal efficiency when the concentration was changed within this range.

This closeness is explained by the possibility of a balance between the amount of residual pollutants and the coagulant's capacity to remove them, as well as the fact that the coagulant's active sites fill up after a certain concentration limit, preventing a significant increase in absorption. The clearance rates ranged from 48 to 56% at pH 5, with no variance in the data. The concentration of 7000 mg/L produced the best results, with a removal rate of 56%; the concentrations of 500 and 3000 mg/L produced the lowest results, with a removal rate of 48%. The intermediate results from the remaining concentrations (1000 and 5000 mg/L) ranged from 51 to 53%. Decreased value of pH resulted in a relative decrease in removal efficiency when compared to pH 7. This could be because excessive acidity weakens the interaction between the coagulant and contaminant molecules. At different concentrations, the outcomes of turbidity removal employing *Citrus limon* coagulant at pH 8 exhibited notable differences. The maximum clearance rate of 65% was attained at the ideal concentration of 1000 mg/L, which was followed by 500 mg/L at 59%. The efficiency decreased to 58% when the concentration was raised to 3000 mg/L and then further declined to 50% and 52% at 5000 and 7000 mg/L, respectively**.**

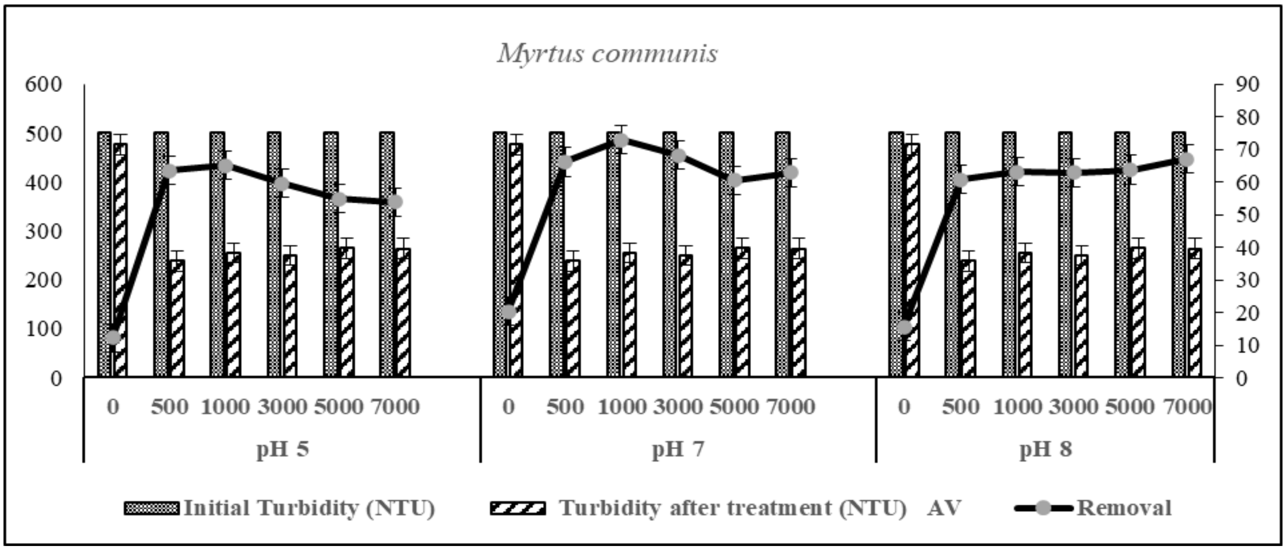


Fig. 3. Turbidity removal efficiency (%) of (*Myrtus communis)* at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate measurements (n = 3), and error bars indicate the standard deviation.

At pH 7, *Myrtus communis* extract was shown to have high turbidity removal efficiency, with the experiment recording 73% at a concentration of 1000 mg/L, which was the highest percentage among all concentrations. At 500 mg/L, the efficiency was good and reached 66%. As the concentration increased, efficiency gradually declined to 68% at 3000 mg/L and 60% at 5000 mg/L, before rising slightly to 62% at 7000 mg/L. This change is shown in Fig. (3). **Hussain and Al-Baldawi (2025)** conducted a study on an Iraqi plant, which is the leaves of the *Myrtus communis* plant, as a green coagulant with a turbidity removal efficiency of 42% at a concentration of 1000 mg/L, compared to the control rate, which was only 22%. The results of *Myrtus communis* showed that the removal efficiency at pH 5 ranged between 53% and 65%, with the highest removal rate of 65% being recorded at a concentration of 1000 mg/L, while the lowest value was recorded at a concentration of 7000 mg/L, at 53%. It is noted that the decrease in efficiency at high concentrations may be related to the increased saturation of the binding sites on the surface of the coagulant, which reduces the effectiveness of the interaction with the suspended kaolin particles. Experiments showed that the efficiency of *Myrtus communis* extract in removing turbidity at pH 8 was relatively similar across different concentrations, with the removal rate varying between 60% at 500 mg/L and 67% at 7000 mg/L, with a slight decline at intermediate concentrations (3000-5000 mg/L). This distribution indicates the good ability of the extract to work under basic conditions, with the possibility of multiple mechanisms such as charge equalization.

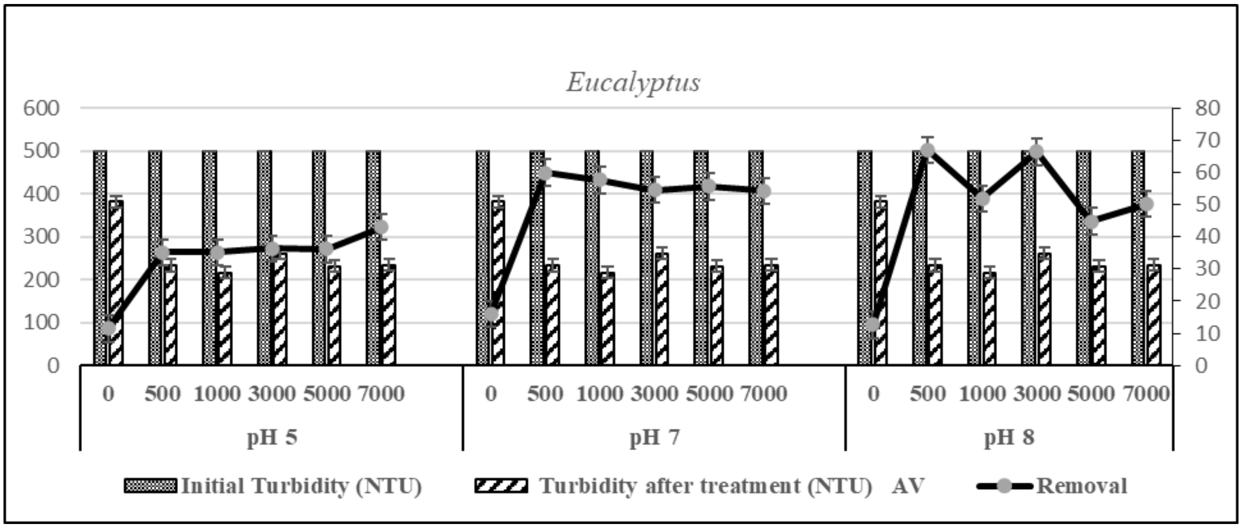


Fig. 4. Turbidity removal efficiency (%) of *(Eucalyptus camaldulensis)* at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate measurements (n = 3), and error bars indicate the standard deviation.

As shown in Fig. (4), the optimal treatment for *Eucalyptus* was achieved at a concentration of 500 mg/L, yielding the maximum turbidity removal efficiency of 59%. Increasing the dosage up to 7000 mg/L led to a gradual decline in efficiency to 54%, likely due to the restabilization of particles caused by excess active molecules. This removal efficiency is lower than that achieved by *Myrtus communis* and *Punica granatum*. This performance gap can be attributed to the lower density or molecular weight of the active coagulating agents (such as specific proteins or polyelectrolytes) in *Eucalyptus* leaves compared to the richer tannin and polyphenolic networks present in *Punica granatum* and *Myrtus communis*, which are more effective in charge neutralization and polymer bridging.

In contrast, the results of the current study showed that eucalyptus leaves gave a higher efficiency of 59% at low concentrations of 500 mg/L and at pH 7, while the efficiency remained within the range of 47–55% at the remaining doses (1000–7000 mg/L). This suggests that the use of *Eucalyptus* in the conditions of this study is more effective and less expensive compared to what was reported by **Salem *et al.* (2023)** in their study. The results in Fig. (4) show that the removal efficiency using *Eucalyptus camaldulensis* at pH 5 was relatively low compared to the values at pH 7 or pH 8, as the ratios at concentrations of 500 and 1000 mg/L ranged from about 35%, and 42% at the highest concentration of 7000 mg/L. This decrease can be attributed to increased accumulation of hydrogen ions in the medium. This result also suggests that pH 5 may alter the surface charge of the adsorbent, reducing its efficiency. At pH 8, plant extracts of *Eucalyptus camaldulensis* showed variation in removal efficiency, with the largest percentage at concentrations of 500 and 3000 mg/L reaching 66%, while it decreased to 51% at a concentration of 1000 mg/L, and reached 44% at a concentration of 5000 mg/L, then rose again to 50% at a concentration of 7000 mg/L, as shown in Fig. (4). This performance reflects that pH 8 may support the effectiveness of active compounds at some concentrations, while limiting them at others.

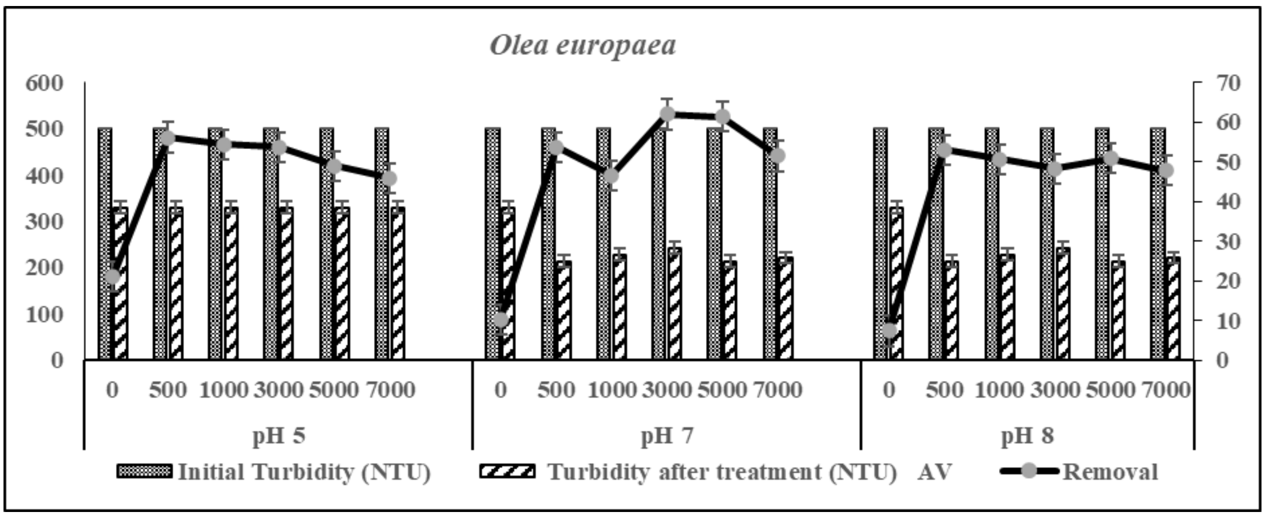


Fig. 5. Turbidity removal efficiency (%) of *(Olea europaea)* at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate measurements (n = 3), and error bars indicate the standard deviation.

The *Olea europaea* extract's performance changed with pH, as shown in Fig. (5). Lower dosages (1000 mg/L) led to a decline to 46%, whereas the optimal dose at pH 7 was found to be 3000 mg/L, providing the maximum turbidity removal effectiveness of 62%. This suggests that whereas lesser dosages were insufficient for full particle coverage, the optimal dose offered the perfect balance of active chemicals for successful floc formation. At pH 5, a clear reduction in efficiency was observed compared to pH 7; the maximum removal was 56% at 500 mg/L and dropped to 45% at 7000 mg/L, suggesting that excess hydrogen ions altered the surface charge of the coagulant. At pH 8, the extract demonstrated a stable and comparable performance across all concentrations, fluctuating narrowly between 53% at 500 mg/L and 47% at 7000 mg/L, indicating that the alkaline medium maintained a relatively constant charge state for the active compounds.

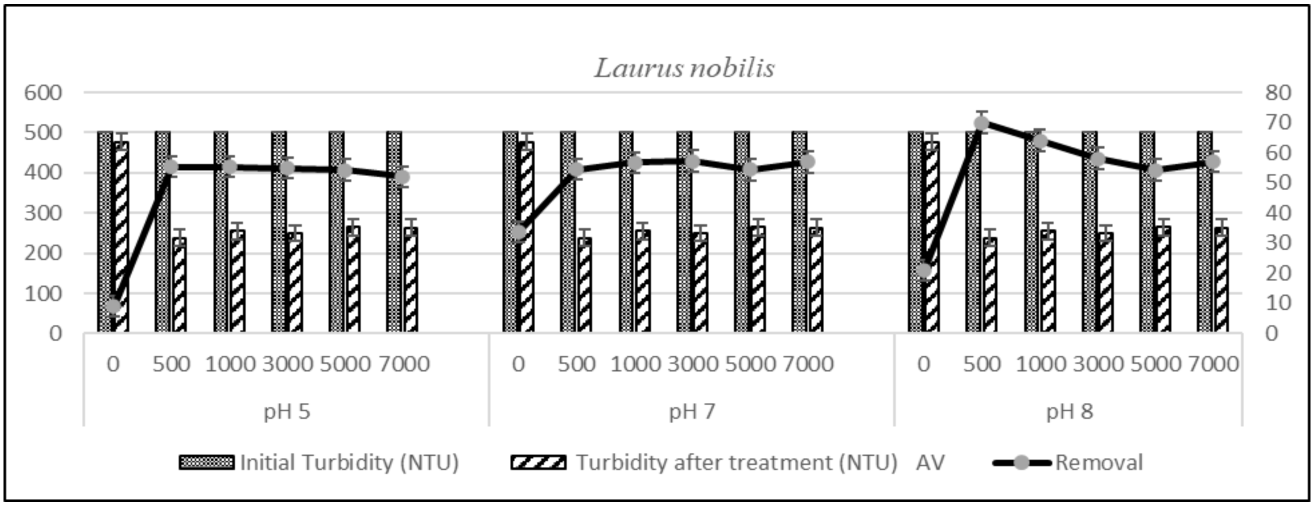


Fig. 6. Turbidity removal efficiency (%) of *(Laurus nobilis)* at different pH levels (5, 7, and 8) and coagulant concentrations (mg/L). Data points represent the means of triplicate measurements (n = 3), and error bars indicate the standard deviation.

At pH 7, *Laurus nobilis* extract showed consistent turbidity removal achievement, with values ranging between 54% and 57% across all concentrations, as shown in Fig. (6). The highest removal rate was found at 3000 mg/L at 57%, followed by similar values at the remaining concentrations (54–56%), indicating that dose change had no significant effect on efficacy at pH 7 and at pH 5. *Laurus nobilis* extract showed consistent achievement across all concentrations, with values at concentrations of 500 and 1000 mg/L being 55%, declining slightly to 54% at concentrations of 3000 and 5000 mg/L, and then ending up at 52% at 7000 mg/L (Fig. 6). This convergence confirms that changing the concentration at pH 5 had no primary effect on efficiency, unlike what was seen in some other plants that showed great sensitivity when changing the dose. This suggests that *Laurus nobilis* compounds retain their coagulant capacity, even with increased hydrogen ions. At a low dosage of 500 mg/L, the *Laurus nobilis* extract at pH 8 had the highest removal efficiency at 69%. This was followed by a value of 64% at 1000 mg/L, before progressively declining to 58% at 3000 mg/L, 54% at 5000 mg/L, and then slightly increasing to 57% at 7000 mg/L (Fig. 6).

CONCLUSION

This study demonstrated that aqueous extracts of specific local Iraqi plants can serve as potential green coagulants for treating synthetic kaolin turbidity. *Punica granatum* and *Myrtus communis* achieved the highest turbidity removal efficiencies, reaching 74% (at 500 mg/L, pH 8) and 73% (at 1000 mg/L, pH 7), respectively. At pH 5, *Olea europaea* and *Citrus limon* showed moderate removal rates of 56%. While these moderate efficiencies (56–74%) show promise for preliminary water clarification, several practical limitations must be addressed before scaling up to real wastewater systems. These include evaluating the residual turbidity of treated water, measuring sludge volume, assessing the potential contribution of organic extracts to COD/TOC levels, and controlling the risk of microbial growth during storage. Furthermore, a direct performance and economic comparison with conventional chemical coagulants like alum or PAC is required. Future validation using real wastewater matrices is necessary to confirm the practical feasibility of these green coagulants.

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