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Effectiveness of Carica Papaya and Raphanus Sativus Seeds as Coagulants for Water Quality Enhancement

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Abstract

In this study, two plant seeds, *Carica papaya* (papaya) and *Raphanus sativus* (radish), were investigated as natural coagulants for treating commercial wastewater. These seeds, known for their bioactive compounds, offer the potential for a safe, cost-effective, and biodegradable solution for improving water quality. The research evaluated the application and performance of *Carica papaya* and *Raphanus sativus* seeds powders for treating commercial wastewater, focusing on key water quality parameters. Jar test experiments demonstrated that *Raphanus sativus* seeds coagulant, at an optimum dosage of 15 mg/L, achieved the highest turbidity removal efficiencies of 85.75% and 81.24% and COD removal efficiencies of 47.62% and 51.72% for wastewater from Points 1 and 2, respectively. In terms of oil removal, *Raphanus sativus* seeds also performed effectively, achieving maximum removal efficiencies of 26.19% at 20 mg/L and 54.60% at 25 mg/L for wastewater from Points 1 and 2, respectively. These results highlight the strong potential of *Raphanus sativus* seeds as an effective natural coagulant, outperforming *Carica papaya* seeds across all tested parameters.

1. Introduction

Water quality had significantly declined due to pollution driven by population growth, industrial activities, and inadequate water management practices [1]. Commercial wastewater has become a major contributor to water pollution because it is often discharged directly into water bodies without proper treatment, leading to eutrophication of surface waters [2]. Commercial wastewater that enters water bodies can originate from activities of residential settlements, restaurants, offices, commerce, and apartments, hence there are various types of contaminants that may be present in commercial wastewater, and some of the parameters that are usually measured in commercial wastewater treatment are oil, turbidity and also Chemical Oxygen Demand (COD).

A high proportion of oil in commercial wastewater is due to poorly maintained grease traps, rising fast-food consumption, and the expansion of food service businesses [3]. Oil forms a layer on the water's surface that prevents oxygen from penetrating, lowering oxygen levels and harming aquatic life [4]. This makes wastewater containing oil significantly more harmful. As oil is a persistent contaminant that can stay in the environment for a

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long time, improper management of wastewater containing oil will have a significant detrimental influence on ecosystems. According to Muhaimin et al. [5], water bodies might exhibit low or even zero dissolved oxygen levels due to Chemical Oxygen Demand (COD). In terms of turbidity, aquatic life will certainly be affected, and other biological processes will also be disrupted by interference with light penetration when highly turbid wastewater is discharged into the environment [6].

Removal of these pollutants from commercial wastewater traditionally relies on chemical coagulants. However, chemical coagulants proved hazardous to the environment when used over extended periods, as they accumulated in the pipeline system and posed significant health risks if ingested [7]. As a result, the introduction of plant-based natural coagulants was proposed as a safer, more environmentally friendly alternative. Extensive research on plant-based natural coagulants has been conducted worldwide.

Research on the effectiveness of coagulants for the coagulation process has found that certain plants act as coagulants through specific coagulation mechanisms while also being environmentally sustainable [8]. However, assessing the effectiveness of different natural coagulants under specific parameters in wastewater remained challenging, as it required a trial-and-error approach. A high dose of coagulants could increase costs and cause sediment to remain in the filtrate, which is hazardous under regulations. Conversely, a low dose of coagulants could cause coagulation to proceed less satisfactorily and produce a lower-than-required quality [9].

Due to these factors, two plant seed types, *Carica papaya* (papaya) and *Raphanus sativus* (radish), were tested as natural coagulants for commercial wastewater treatment in this research. *Carica papaya* seeds are believed to have significant potential as a bio-coagulant for treating raw or contaminated water [10]. Papaya seeds are rich in proteins and functional groups like $-NH_2$ and $-COOH$, which facilitate coagulation through mechanisms such as charge neutralisation and particle bridging [11]. Hosseini [12] reported that active components of *Carica papaya* seeds, such as polysaccharides, fibre, and proteins, were effective in reducing turbidity in water. *Raphanus sativus*, or white radishes, on the other hand, are an extensively grown root vegetable, and they are high in beneficial nutrients like vitamins, minerals, and carbohydrates that support human health [13].

Turbidity, Chemical Oxygen Demand (COD), and oil content were selected as the primary water quality parameters for evaluating coagulation performance in this study. These indicators are widely recognised as reliable measures of treatment efficiency. Turbidity provides a direct indication of suspended particle concentration and serves as a practical proxy for TSS reduction. Likewise, COD and oil content represent the removal of organic and hydrophobic pollutants, both of which are sensitive to pH conditions during coagulation–flocculation processes. Improvements in these parameters therefore provide indirect but reliable evidence of the effectiveness of the coagulants under the tested conditions. This study could promote the use of *Carica papaya* and *Raphanus sativus* seeds as natural coagulant alternatives to synthetic coagulants. The key significance lies in determining the optimal dosage of *Carica papaya* and *Raphanus sativus* seeds as coagulants, as the ideal dosage could greatly enhance the efficiency of wastewater treatment operations.

2. Methodology

This study was designed primarily as a series of laboratory experiments, with limited reference to fieldwork, to evaluate the effectiveness of *Carica papaya* and *Raphanus sativus* seeds as natural coagulants for improving water quality. The methodology and workflow were structured to ensure a systematic, logical approach, guiding data collection and analysis with appropriate techniques. This framework ensured that the data obtained were accurate, relevant, and aligned with the research objectives. Overall, the methodology provided transparency, reliability, and reproducibility, thereby enhancing the validity and significance of the study findings.

2.1 Study Area and Sampling Points

The selected site for wastewater sampling was a drainage in Seksyen 7, Shah Alam, Selangor, as shown in Fig. 1. The shop lots and restaurants near the lake generate significant amounts of wastewater daily due to the high volume of customers. The water surface displayed a thick oil layer, and numerous small particulate matters that contributed to the water's cloudy appearance (see Fig. 2). Organic waste such as food scraps, grease, and other biodegradable materials elevated the Chemical Oxygen Demand (COD) levels in the wastewater. For this study, two sampling points were selected along the drainage. The sampling points were spaced 170 meters apart. Water samples were collected during peak hours to ensure pollutant and contamination levels were at their highest, representing the pollutant load that most wastewater treatment systems would need to handle.

2.2 Preparation of *Carica papaya* and *Raphanus sativus* Seeds as Coagulant

Carica papaya and *Raphanus sativus* seeds were sourced through an online commercial platform, where various seed types were reviewed, and the most suitable options were carefully selected for quality and availability. Upon arrival, the raw seeds were first cleaned by rinsing thoroughly with clean water to remove surface impurities, dust, and other contaminants that could interfere with subsequent preparation. After rinsing, the seeds were left to air-dry naturally under direct sunlight until all visible surface moisture had evaporated. This drying step was crucial for preventing microbial growth and facilitating the grinding process.

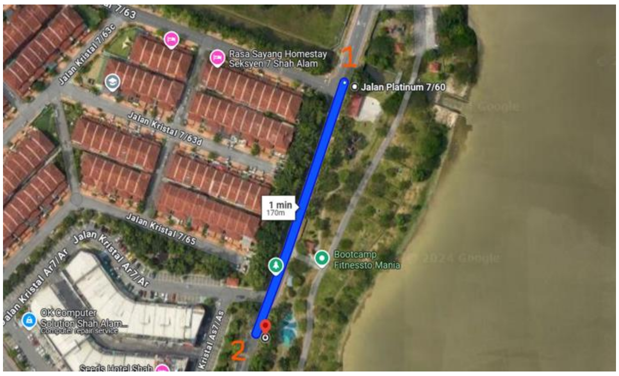

Fig. 1 *Locations of Points 1 and 2 for water samplings*

(a) **(b)**

Fig. 2 *Condition of the water sample at (a) Point 1; and (b) Point 2*

The dried seeds were then pulverised using a domestic blender, as demonstrated in similar studies [14], to produce a fine powder. The seed powder was subsequently sieved using a 600 µm laboratory sieve [14]. Ensuring that the particle size remained below 600 µm was considered essential, as smaller particles increase surface area, thereby enhancing the solubility and release of the active coagulating compounds when mixed with water [15].

To prepare the natural coagulant solutions, an initial approach based on Amran et al. [11] was adopted, in which 500 mg of seed powder was dissolved in 500 mL of distilled water to obtain a 1 g/L coagulant solution. However, to achieve higher effectiveness and consistency, this study employed a modified preparation method. Specifically, 1 g of *Carica papaya* and *Raphanus sativus* seeds powder was separately mixed with 500 mL of distilled water using a magnetic stirrer, resulting in a 2 g/L coagulant stock solution. The use of a magnetic stirrer ensured uniform dispersion of the seed particles and promoted better extraction of the active constituents into the solution.

Before filtration, the crude solutions were passed through a 63 µm sieve to remove coarse particles and reduce the solids load. This pre-filtration step was necessary to avoid clogging of the filter paper and to expedite the subsequent filtration process, as also recommended in earlier work [16]. Following this, each solution was carefully filtered through standard filter paper to obtain a clear coagulant stock solution, free from large particulate matter.

The prepared stock solutions were then stored in a refrigerator at low temperature to maintain their stability and prevent microbial degradation until required for coagulation experiments. To ensure the effectiveness and freshness of the natural coagulants, new batches of seed powders were prepared monthly, in accordance with the recommendations of Amran et al. [17]. This approach ensured consistent quality of the coagulant solutions throughout the study.

2.3 Coagulation Process

The treatment of commercial wastewater by coagulation was carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (published by APHA) [18]. This research aimed to determine the optimal dosage of *Carica papaya* and *Raphanus sativus* seeds as coagulants. This was because different coagulants from the seeds required different dosage ranges for optimal coagulation of the wastewater. A range of dosages for both of the coagulants were mixed with the prepared wastewater using the jar test apparatus through trial-and-error experiments and it was found that the suitable coagulant dosages that should be used for *Raphanus sativus* seeds were of 5, 10, 15, 20, 25, 30 mg/L meanwhile the suitable *Carica papaya* seeds coagulants were 7, 14, 21, 28, 35 and 42 mg/L.

Hence, the appropriate coagulant dosages were added to beakers 1, 2, 3, 4, 5, and 6, respectively. Both the coagulant and wastewater samples were first mixed quickly at 150 rpm for 1 minute, and the wastewater sample was then slowly mixed at 50 rpm for 20 minutes [19]. The water samples were left to settle for 20 minutes. A blank sample was also prepared and labelled as 0.

2.4 Parameters Determination

Measuring the turbidity level of each water sample at different dosages involved using a turbidity meter in the laboratory [20]. 15 mL of each coagulated wastewater sample, including the blank sample, was transferred into seven 15 mL turbidity sample cells. The NTU (Nephelometric Turbidity Units) reading was taken and recorded.

For measuring Chemical Oxygen Demand (COD) in wastewater samples, the COD reactor was preheated to 150 °C. COD concentration was determined by reacting the samples with potassium dichromate, which acted as the oxidising agent. Using a mechanical pipette, 2 mL of each wastewater sample was added to seven individual COD digestion vials. The vials were securely sealed and inverted several times to ensure proper mixing. Subsequently, the vials were placed in the preheated COD reactor and digested at 150 °C for 2 hours [21]. After digestion, the vials were allowed to cool to room temperature. The COD values for each vial were measured with a spectrophotometer and recorded in mg/L.

Oil from the coagulated wastewater was extracted with n-hexane. The solvent was added at a 1:20 ratio relative to the wastewater volume, using 25 mL of n-hexane per 500 mL of wastewater. The mixture was transferred into a separatory funnel to allow phase separation between the oil and water layers. After settling for 10 minutes, the aqueous layer was slowly drained from the funnel. An aluminium pan was pre-weighed, and the extracted oil layer was transferred into the pan and heated at 60 °C for 60 minutes to evaporate the n-hexane. The pan containing the dried oil residue was then reweighed using an analytical balance, and the final mass of the extracted oil was recorded.

3. Results and Discussion

To determine the optimum dosage for both *Carica papaya* and *Raphanus sativus* seeds coagulants, the removal efficiency graphs were carefully analysed. On each graph, the peak point indicating the highest removal efficiency was identified. This peak represented the optimal dosage at which each coagulant, *Carica papaya* and *Raphanus sativus* seeds, performed most effectively for a given parameter. Identifying the optimal dosage is critical because it ensures maximum contaminant removal and yields the highest-quality treated wastewater [22].

3.1 Turbidity

As shown in Fig. 3, the *Raphanus sativus* seeds coagulant achieved turbidity removal efficiencies of 85.75% at 2.81 NTU for wastewater from Point 1 and 81.24% at 6.21 NTU for wastewater from Point 2. These values were obtained at an optimum dosage of 15 mg/L after several trial-and-error iterations during the coagulation process.

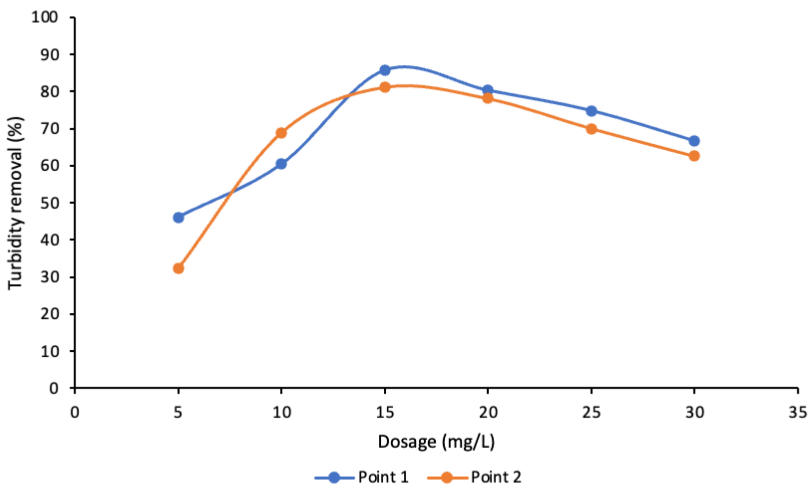

Fig. 3 *Percentage of turbidity removal for Raphanus sativus seeds coagulant dosage*

To further examine the effects of dosage and sampling point on turbidity removal, a two-way ANOVA was conducted using dosage as a continuous factor and sampling point (Point 1 vs. Point 2) as a categorical factor. The two-way ANOVA results (see Table 1) indicate that *Raphanus sativus* seeds dosage had a significant effect on turbidity removal (p = 0.023), confirming dosage as the key factor influencing treatment performance. Although removal efficiency at Point 1 was consistently higher than at Point 2, the difference was not statistically significant (p = 0.111). Similarly, the interaction between dosage and point was not significant, indicating that both points followed a comparable dosage–response trend. These findings demonstrate that *Raphanus sativus* seeds are effective at reducing turbidity, with dosage optimisation being the most important factor, while spatial variation between sampling points had minimal statistical influence.

Fig. 4 shows that the *Carica papaya* seeds coagulant achieved maximum turbidity removal efficiencies of 58.27% (8.23 NTU) and 50.24% (16.47 NTU) for wastewater samples from Points 1 and 2, respectively, at an optimum dosage of 28 mg/L. The initial turbidity values before treatment were 19.72 NTU for Point 1 and 33.10 NTU for Point 2.

Table 1 *Two-way ANOVA for the effect of Raphanus sativus seeds dosage and sampling point on turbidity removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Point (1 vs 2)	1	1276.26	1276.26	3.05	0.111
Dosage (mg/L)	1	3020.7	3020.7	7.23	0.023 *
Dosage × Point	1	368.39	368.39	0.88	0.37
Residual (Error)	10	4178.94	417.89	-	-
Total	13	8838.28	-	-	-

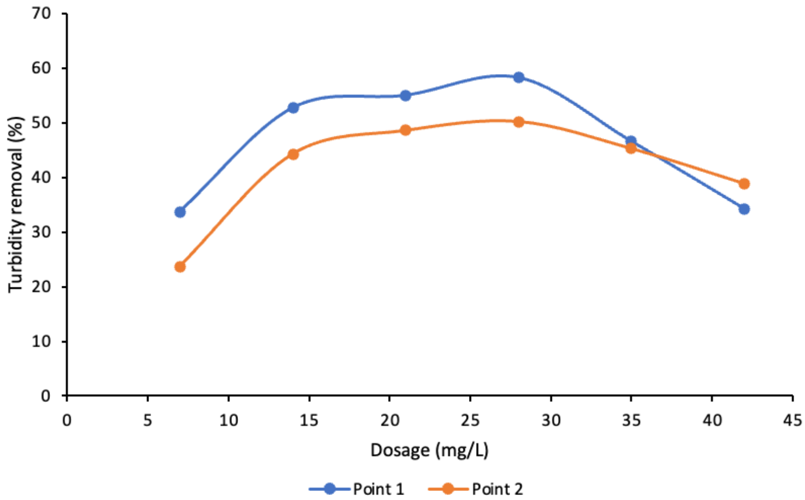

Fig. 4 *Percentage of turbidity removal for Carica papaya seeds coagulant dosage*

The two-way ANOVA results (see Table 2) demonstrate that *Carica papaya* seeds dosage significantly influenced turbidity removal (p = 0.038), highlighting the importance of dosage optimisation. Although Point 1 consistently achieved slightly higher removal than Point 2, the difference was not statistically significant (p = 0.647). Similarly, the interaction between dosage and point was not significant, indicating that both sampling points exhibited comparable dosage–response patterns.

Based on these findings, the *Raphanus sativus* seeds coagulant demonstrated a higher turbidity removal efficiency compared to the *Carica papaya* seeds coagulant. Furthermore, the optimum dosage for *Raphanus sativus* seeds coagulant, 15 mg/L, was considerably lower than that for *Carica papaya* seeds coagulant, 28 mg/L, to achieve their respective peak performance. Overall, the results indicate that *Raphanus sativus* seeds coagulant outperformed *Carica papaya* seeds coagulant in turbidity removal efficiency throughout this study.

Table 2 *Two-way ANOVA for the effect of Carica papaya seeds dosage and sampling point on turbidity removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	*p*-value
Point (1 vs 2)	1	62.37	62.37	0.22	0.647
Dosage (mg/L)	1	1601.15	1601.15	5.74	0.038 *
Dosage × Point	1	18.04	18.04	0.06	0.805
Residual (Error)	10	2791.64	279.16	-	-
Total	13	4473.21	-	-	-

3.2 Chemical Oxygen Demand (COD)

The experimental results further demonstrated that the *Raphanus sativus* seeds coagulant achieved a Chemical Oxygen Demand (COD) removal efficiency of 47.62% (22 mg/L) for wastewater from Point 1 and 51.72% (28 mg/L) for wastewater from Point 2, at an optimum dosage of 15 mg/L, as shown in Fig. 5.

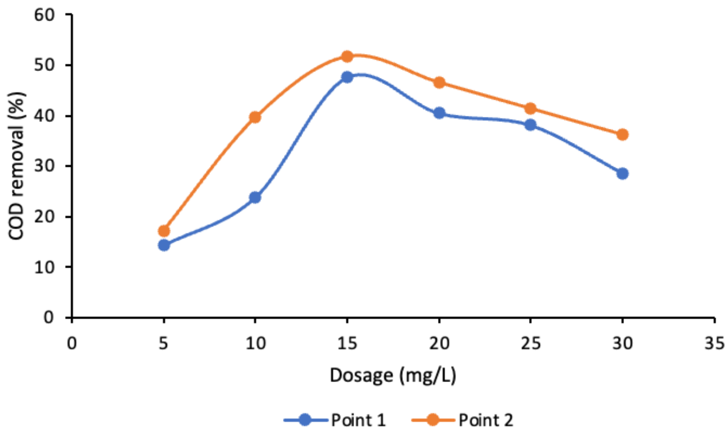

Fig. 5 *Percentage of COD removal for Raphanus sativus seeds coagulant dosage*

The two-way ANOVA results for the updated *Raphanus sativus* seeds dataset are presented in Table 3. The analysis revealed that dosage had a statistically significant effect on COD removal efficiency ($p = 0.012$), confirming that the amount of *Raphanus sativus* seeds coagulant is the primary factor influencing treatment performance. In contrast, the effect of sampling point (Point 1 vs. Point 2) was not significant ($p = 0.453$), suggesting that the average removal efficiency did not differ substantially between the two locations. Similarly, the interaction between dosage and point was not significant ($p = 0.895$), indicating that the dosage–removal trend was consistent across both sampling points.

Table 3 *Two-way ANOVA for the effect of Raphanus sativus seeds dosage and sampling point on COD removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	*p*-value
Point (1 vs 2)	1	113.66	113.66	0.61	0.453
Dosage (mg/L)	1	1758.4	1758.4	9.43	0.012*
Dosage × Point	1	3.4	3.4	0.02	0.895
Residual (Error)	10	1865.21	186.52	-	-
Total	13	3740.67	-	-	-

Although both points exhibited a similar response to increasing dosage, the magnitude of removal varied slightly. Beyond these levels, a gradual decline in performance was observed, consistent with the typical coagulation–flocculation pattern, in which overdosing can cause charge reversal and particle restabilization. In comparison, Fig. 6 shows that the *Carica papaya* seeds coagulant achieved COD removal efficiencies of 30.95% (29 mg/L) and 31.03% (40 mg/L) for wastewater from Points 1 and 2, respectively, with an optimum dosage of 28 mg/L. The initial COD levels prior to treatment were 42 mg/L for Point 1 and 58 mg/L for Point 2.

The results of the two-way ANOVA for *Carica papaya* seeds are presented in Table 4. The analysis showed that dosage had a statistically significant effect on COD removal efficiency (p = 0.021), confirming that *Carica papaya* seeds dosage is an important factor influencing coagulation performance. In addition, the effect of the sampling point was also significant (p = 0.034), indicating that the removal efficiency differed between the two locations. This demonstrates *that the performance of Carica papaya* seeds was more favourable at Point 1, possibly due to differences in the initial COD concentrations of the water samples.

The interaction between dosage and point was not significant (p = 0.363), suggesting that while the absolute removal values differed between the two points, the overall trend in dosage–removal response was consistent. Both points exhibited an increase in removal up to an optimum dosage, followed by a gradual decline at higher dosages, reflecting the typical coagulation–flocculation behaviour associated with overdosing. Overall, the comparison between the two natural coagulants revealed that the *Raphanus sativus* seeds coagulant was more effective at COD removal, achieving higher efficiency while requiring a significantly lower dosage than the *Carica papaya* seeds coagulant.

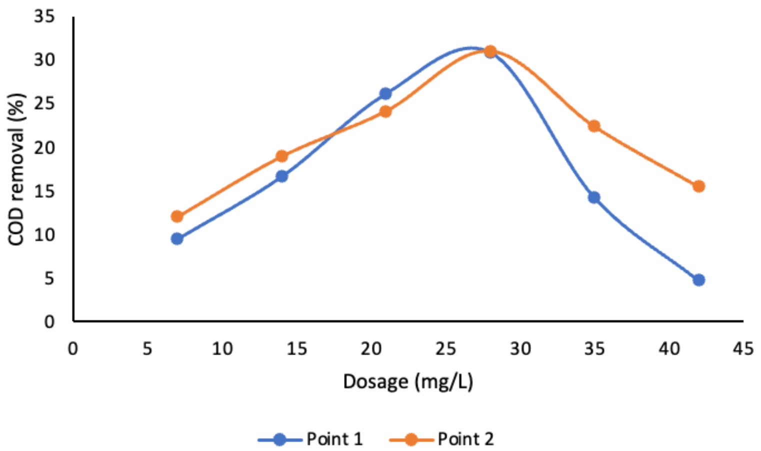

Fig. 6 *Percentage of COD removal for Carica papaya seeds coagulant dosage*

Table 4 *Two-way ANOVA for the effect of Carica papaya seeds dosage and sampling point on COD removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	*p*-value
Point (1 vs 2)	1	842.74	842.74	5.99	0.034 *
Dosage (mg/L)	1	1055.31	1055.31	7.51	0.021 *
Dosage × Point	1	127.5	127.5	0.91	0.363
Residual (Error)	10	1405.73	140.57	-	-
Total	13	3431.29	-	-	-

3.3 Oil and Grease

The experiments conducted in this study further confirmed the effectiveness of *Raphanus sativus* seeds coagulant in removing oil from wastewater. As shown in Fig. 7, the *Raphanus sativus* seeds coagulant achieved the highest oil removal efficiency of 26.19% for wastewater from Point 1 at an optimum dosage of 20 mg/L, and 54.60% for wastewater from Point 2 at an optimum dosage of 25 mg/L.

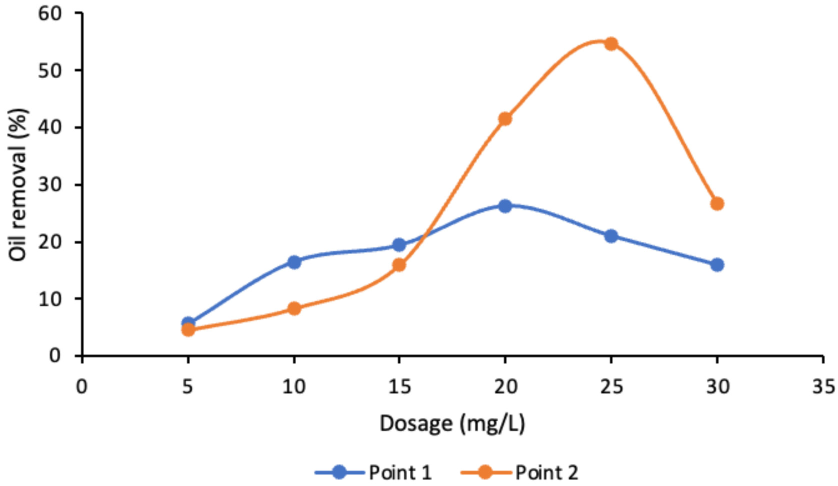

Fig. 7 *Percentage of oil and grease removal for Raphanus sativus seeds coagulant dosage*

To further examine the effects of dosage and sampling point on oil removal, a two-way ANOVA was conducted using dosage as a continuous factor and sampling point (Point 1 vs. Point 2) as a categorical factor. The results (see Table 5) showed that dosage had a highly significant effect on oil removal efficiency (p = 0.003), confirming that the amount of *Raphanus sativus* seeds coagulant strongly influences treatment performance. In contrast, the main effect of sampling point was not statistically significant (p = 0.253), indicating that the average removal efficiency between Points 1 and 2 did not differ greatly. Similarly, the interaction between dosage and sampling point was not significant (p = 0.138), suggesting that the overall trend of dosage–removal response was broadly consistent at both points.

At both points, removal efficiency increased with dosage up to an optimum level, then declined at higher dosages, consistent with the typical coagulation–flocculation trend. However, the magnitude of removal was greater at Point 2, where efficiency peaked at 54.6% at 25 mg/L, compared to Point 1, which achieved a maximum of 26.19% at 20 mg/L. While these differences were not statistically significant in the two-way ANOVA, they highlight that local water characteristics, such as initial oil concentration, may affect the magnitude of removal achieved at a given dosage.

Table 5 *Two-way ANOVA for the effect of Raphanus sativus seeds dosage and sampling point on oil removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Dosage (mg/L)	1	1618.84	1618.84	15.14	0.003 **
Point (1 vs 2)	1	157.12	157.12	1.47	0.253
Dosage × Point	1	278.62	278.62	2.61	0.138
Residual (Error)	10	1068.93	106.89	—	—
Total	13	3123.51	—	—	—

In comparison, Fig. 8 shows that the *Carica papaya* seeds coagulant exhibited lower oil removal efficiencies of 25.26% and 31.83% for wastewater from Points 1 and 2, respectively, at optimum dosages of 14 mg/L and 28 mg/L. The initial oil extract weights before treatment were 0.1073 g for Point 1 and 0.2174 g for Point 2. These findings highlight the superior performance of *Raphanus sativus* seeds coagulant in both oil removal efficiency and lower dosage requirement, and the results are consistent with the study by Khader et al. [15].

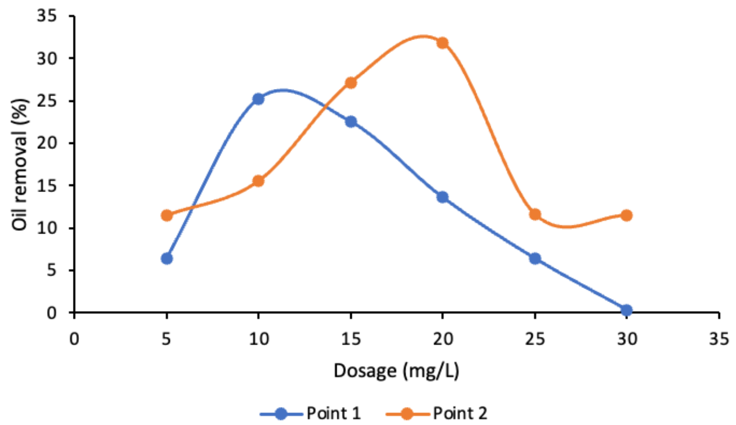

Fig. 8 *Percentage of oil and grease removal for Carica papaya seeds coagulant dosage*

A two-way ANOVA was performed to evaluate the effects of *Carica papaya* seeds dosage and sampling point on oil removal efficiency (see Table 6). The results showed that neither dosage (p = 0.633) nor point (p = 0.421) had a statistically significant effect on removal efficiency, nor did the interaction between dosage and point (p = 0.472). This indicates that, unlike *Raphanus sativus* seeds, the oil removal performance of *Carica papaya* seeds was not strongly influenced by the applied dosage or the sampling location.

Table 6 *Two-way ANOVA for the effect of Carica papaya seeds dosage and sampling point on oil removal efficiency*

Source	df	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Point (1 vs 2)	1	85.26	85.26	0.7	0.421
Dosage (mg/L)	1	29.32	29.32	0.24	0.633
Dosage × Point	1	67.76	67.76	0.56	0.472
Residual (Error)	10	1211.63	121.16	—	—
Total	13	1393.97	—	—	—

Throughout this study, the *Raphanus sativus* seeds coagulant consistently outperformed the *Carica papaya* seeds coagulant across all three evaluated parameters: turbidity, Chemical Oxygen Demand (COD), and oil removal efficiency. In addition to its superior performance, the *Raphanus sativus* seeds coagulant required lower doses than *Carica papaya* seeds, demonstrating its efficiency and practicality. Therefore, *Raphanus sativus* seeds coagulant can be regarded as an effective natural alternative for enhancing wastewater quality, particularly in water treatment plants. Using a high coagulant dosage can increase treatment costs and may result in residual sediment. On the other hand, an insufficient coagulant dose may lead to ineffective coagulation, producing treated water of substandard quality [9].

Although this study did not conduct FTIR, SEM, or zeta potential characterisation of the seed powders, the structural and functional properties of *Carica papaya* and *Raphanus sativus* seeds have been well documented in previous research. For instance, Amran et al. [11] and Dewi & Rahmayanti [23] reported the presence of hydroxyl, carbonyl, carboxyl, and amine functional groups in *Carica papaya* seeds, which are closely associated with their coagulation activity. In addition, Amran et al. [24] confirmed the role of proteins and surface charge in enhancing particle destabilisation and floc formation. Similarly, Guragain et al. [25] demonstrated, using FTIR and SEM analyses, that *Raphanus sativus* seeds possess functional groups and morphological features that contribute to pollutant removal. Given that these properties are consistently described in the literature, the present work focused on evaluating the coagulation performance of *Carica papaya* and *Raphanus sativus* seeds in improving water quality. Future research should, however, include direct material characterisation of the seed powders used in order to strengthen the correlation between functional groups and coagulation efficiency.

4. Conclusion

This study compared the effectiveness of *Carica papaya* and *Raphanus sativus* seeds as natural coagulants for treating wastewater from two sampling points. Both showed potential in removing turbidity, COD, and oil, but *Raphanus sativus* seeds consistently performed better. It achieved higher removal rates for turbidity (up to 85.75%), COD (up to 51.72%), and oil (up to 54.60%) than the *Carica papaya* seeds coagulant. These results suggest that *Raphanus sativus* seeds is a more efficient and promising natural coagulant, offering a low-cost and sustainable alternative to conventional chemical treatments. It is recommended that future studies should optimise dosage and conditions, test the coagulants at a larger scale, and assess sludge characteristics. Combining these coagulants with other natural coagulants and evaluating cost-effectiveness can further support their use as sustainable alternatives.

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Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Azinoor Azida Abu Bakar, Muhammad Afiq Aiman Mohd Yusof;* ***Data collection:*** *Muhammad Afiq Aiman Mohd Yusof;* ***Analysis and interpretation of results:*** *Azinoor Azida Abu Bakar, Herda Balqis Ismail;* ***Draft manuscript preparation:*** *Muhammad Khairudin Khalil, Azinoor Azida Abu Bakar. All authors reviewed the results and approved the final version of the manuscript.*

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