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Performance of Plant-Based Coagulants in Removing Turbidity and Chemical Oxygen Demand (COD) in Industrial Wastewater: A Systematic Review and Meta-Analysis

Aimi Shazreen Shukri[1], Fauzi Baharudin[1], Jalina Kassim[1], Nor Amani Filzah Mohd Kamil[2], & Nurhidayah Hamzah[1*]

[1] School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

[2] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussien Onn Malaysia, Batu Pahat, Johor, Malaysia

*Corresponding author Email address: nurhidayah0527@uitm.edu.my

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Abstract

Industrial effluent contains high concentrations of pollutants, such as heavy metals, which can cause risks to human health and the ecosystem. Chemical coagulants such as aluminum and iron salts are typically used as a coagulant in the wastewater treatment plant. The effectiveness of chemical coagulants is good in the clarification of wastewater, but excessive use is not sustainable and toxic. This study focuses on the removal of turbidity and chemical oxygen demand (COD) of various industrial effluents, including dairy wastewater, textile wastewater, paper, and paper mill industry, by comparing the removal between plant-based and chemical coagulants. The study aims to quantify the ability of plant-based coagulants to remove turbidity and COD in industrial effluents. A systematic review was used to conduct this study by using a systematic search strategy (PRISMA) in the relevant databases, which are Scopus, Web of Science, and Google Scholar. Only experimental studies that test both plant-based and chemical coagulants were chosen to proceed with meta-analysis to validate the efficiency of the plant-based coagulant to remove turbidity and COD in different industrial effluents by using Cochrane RevMan 5.4 software. Twenty-five articles were evaluated, and high heterogeneity was found among those studies. The mean difference (MD) and 95% confidence interval (CI) showed a significantly increasing percentage of turbidity and COD removal by plant-based coagulant by -1.64 % (-3.49, 0.21) and -5.39% (-8.85, -1.93) respectively for all wastewaters. The result supports the application of plant-based coagulant to sustain wastewater treatment due to its eco-friendly, non-toxic, biodegradable, and capability to sustain the pH of water after treatment.

Keywords: Chemical coagulants, industrial wastewater, natural coagulants, organic pollutant, plant-based coagulant, sustainability

1. Introduction

Rapid industrialization has posed multiple environmental challenges because of the generation of wastewater by numerous industrial processes. Indiscriminate discharge of such wastewater, with or without adequate treatment, can cause water contamination and land pollution (Gautam & Saini, 2020). The major high-risk components of industrial effluent are mainly additives, dyes, bleaching agents, liquids, acids, and bases that can cause an effect on the environment as well as aquatic animals. The possible concern is that the wastewater that comes from the industrial process may contain suspended particles which can affect human health (Ahmed et al., 2020; Raza et al., 2023). Coagulation and flocculation processes are commonly utilized in water and wastewater treatment. The use of coagulants in the coagulation-flocculation process is important since it can eliminate highly suspended solids and colloidal particles in the water, thereby improving the consistency of the treated water. The common inorganic coagulants utilized in water and wastewater treatment are aluminum sulfate, ferric sulfate, and iron (III) chloride due to their effectiveness in removing turbidity and particles in water (de Paula et al., 2018). Despite their effectiveness, some drawbacks regarding the use of these coagulants, such as large sludge production, costly maintenance, adverse impact on human health as well as a major impact on the pH of treated water (Zaidi et al., 2019). Due to this, excessive non-biodegradable sludge generation is a critical concern in the use of chemical coagulants for wastewater treatment, especially in industrial effluent. Strong demand and interest in the coagulation process have boosted the discovery of new-generation coagulants with enhanced coagulation capacity and productivity. This involves the scope for plant-based coagulants as an alternative to chemical-based coagulants in the sense of environmental use and sustainable development (Ang & Mohammad, 2020). The possible ways to mitigate these issues are by using plant-based coagulants as a suitable substitute for the reduction of turbidity in wastewater treatment. These coagulants must be economical, biodegradable, and less toxic compared to chemical coagulants. Moreover, minimal sludge handling and low cost of treatment are observed since less sludge is produced by using a plant-based coagulant (Balbinoti et al., 2023; Maurya & Daverey, 2018).

Many studies have shown the potential use of plant-based coagulants to remove impurities in wastewater, but fewer studies were found in databases that systematically reviewed plant-based coagulants, especially in different industrial wastewater. Since different industrial wastewater contains different impurities/parameters concern, it is essential to identify how plant-based coagulants respond to different industrial wastewater effluent. Therefore, a systematic review and meta-analysis were conducted to extensively identify the potential of plant-based coagulants to remove turbidity and COD. This study emphasizes the performance and viability of locally sourced plants as an alternative to chemical coagulants in industrial effluent treatment processes. Paper, dairy, and the textile industry were chosen as the three types of industrial wastewater to be analyzed in this study. As a result, this study will benefit researchers by shedding some light on the strength of the plant-based coagulant in removing turbidity and COD based on their industrial wastewater concern.

A systematic review can provide a valid response to a research question by finding and summarizing individual studies that give information relevant to the topic. Moreover, it is often applied in research studies to summarize the findings of randomized trials that examine the impact of an intervention (Aromataris & Pearson, 2014). It also can include summary research on the accuracy of diagnostic tests, research on the prevalence of clinical conditions, research on prognostic factors, and others. Meanwhile, meta-analysis is a statistical technique for combining numerical data from various studies into individual studies. The findings from the individual studies and the overall estimate from the meta-analysis are usually indicated in a graph called a forest plot (Shorten & Shorten, 2013). A forest plot is a graphical representation of individual results for each included study and meta-analysis findings, together with the combination of meta-analysis results. The heterogeneity can be seen from the plot on the graph with the findings of the studies. The forest plot includes a quick visual representation of the overall effect estimate and heterogeneity, which is effective in performing a meta-analysis (Lin et al., 2017). Other than that, meta-analysis can improve statistical power by combining results from 2 or more studies. A meta-analysis may be completed if the included studies are sufficiently similar, and the findings can be provided in the same framework. The results of the meta-analysis can be useful in determining the effect of intervention treatment and suggesting another method to be used. This aligned with a study made by Zhang et al., (2023) in which specific treatment can be recommended for wastewater-based studies according to meta-analysis results.

2. Methods

In this section, the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) were followed to guide the systematic literature review process. This method was chosen based on commonly utilized guidelines in the environmental management field (Shaffril et al., 2018). Moreover, it offers three benefits which are 1) research questions that permit systematic research to be more defined, 2) it identifies inclusion and exclusion criteria, and 3) the ability to examine a large database of scientific literature in a specific time (Sierra-Correa & Kintz, 2015).

2.1 The Resources

The resources of this review were focused on two primary databases, which are Web of Science and Scopus. These sources consisted of actual events from the author and original research done in the field, and it is an important requirement in the systematic literature review. Web of Science is a main database consisting of a total of N33,000 journals as well as coverage for over 256 disciplines together with subjects that related to studies about the environment, interdisciplinary social sciences, and social issues with development and planning. The second database used in this review study is Scopus. It is one of the largest citation databases of peer-reviewed literature, with N22,800 journals from 5000 publishers worldwide. This database also consists of various subject areas such as environmental sciences, social science and agriculture, and biological sciences. The secondary source used in the research was Google Scholar to deliberate studies that were originally presented in other sources and written for a broad audience since it included summaries of studies related to the topic.

2.2 Eligibility and Exclusion Criteria

In this section, only articles from journals with empirical data were selected, which means review articles, book series, and chapters in books are all excluded as the literature type. Secondly, non-English publications were also excluded to avoid confusion and difficulty in translating. Only publication in English was considered. Thirdly, a timeline of 10 years is selected (between 2011 to 2021) to observe the evolution of research and related publications. Lastly, only articles that align with the objective, including the cause-effects of plant-based coagulants and chemical coagulants in different industrial wastewater. Other than that, the outcome, which is to measure the turbidity and COD of the water, is included. These parameters are important in maintaining the quality of water as well as maintaining the sustainability of the environment since COD and turbidity are overviewed as emerging organic pollutants, especially in industrial wastewater (Fereja et al., 2020; Nair et al., 2021; Owodunni & Ismail, 2021).

2.3 Systematic Review Process

The systematic review process consisted of four stages of the process, as shown in Figure 1. The initial phase of the review identified the keywords that can be used for the search purpose. Based on previous studies and thesaurus, similar keywords related to coagulation removal efficiency, plant-based coagulant or natural coagulant, and industrial effluent were used. Duplicate articles were removed at this stage. The complete search string that used the Boolean Method in searching the databases is shown in Table 1.

Table 1. The Search String used for the Systematic Review

Databased	Keyword used
Scopus	TITLE-ABS-KEY ("performance" OR "efficiency" OR "removal" AND "natural coagulant" OR "plant-based coagulant" OR "bio-solvent" OR "bio-coagulant" AND "industry* wastewater")
Web of Science	TS=(("performance" OR "efficiency" OR "removal")AND ("natural coagulant" OR "plant-based coagulant" OR "bio-solvent" OR "bio-coagulant") AND ("industry* wastewater"))
Google Scholar	Performance of Plant-Based Coagulants in Removing Turbidity and Chemical Oxygen Demand (COD) in Industrial Wastewater

For the identification stage, a total of 1233 irrelevant articles were removed. After the first stage, the screening process was conducted. A total of 83 articles were eligible to be reviewed then a total of 1233 articles were removed. The third stage is eligibility, where the articles were accessed. A total of 25 articles were excluded since some of the articles did not focus on the research objective study. At this stage of the systematic review, a total of 28 articles were excluded since some of the studies had ambiguous data, were not qualitative, and overlapped. The final stage of the systematic review resulted in a total of 25 articles being used for qualitative study before proceeding to meta-analysis.

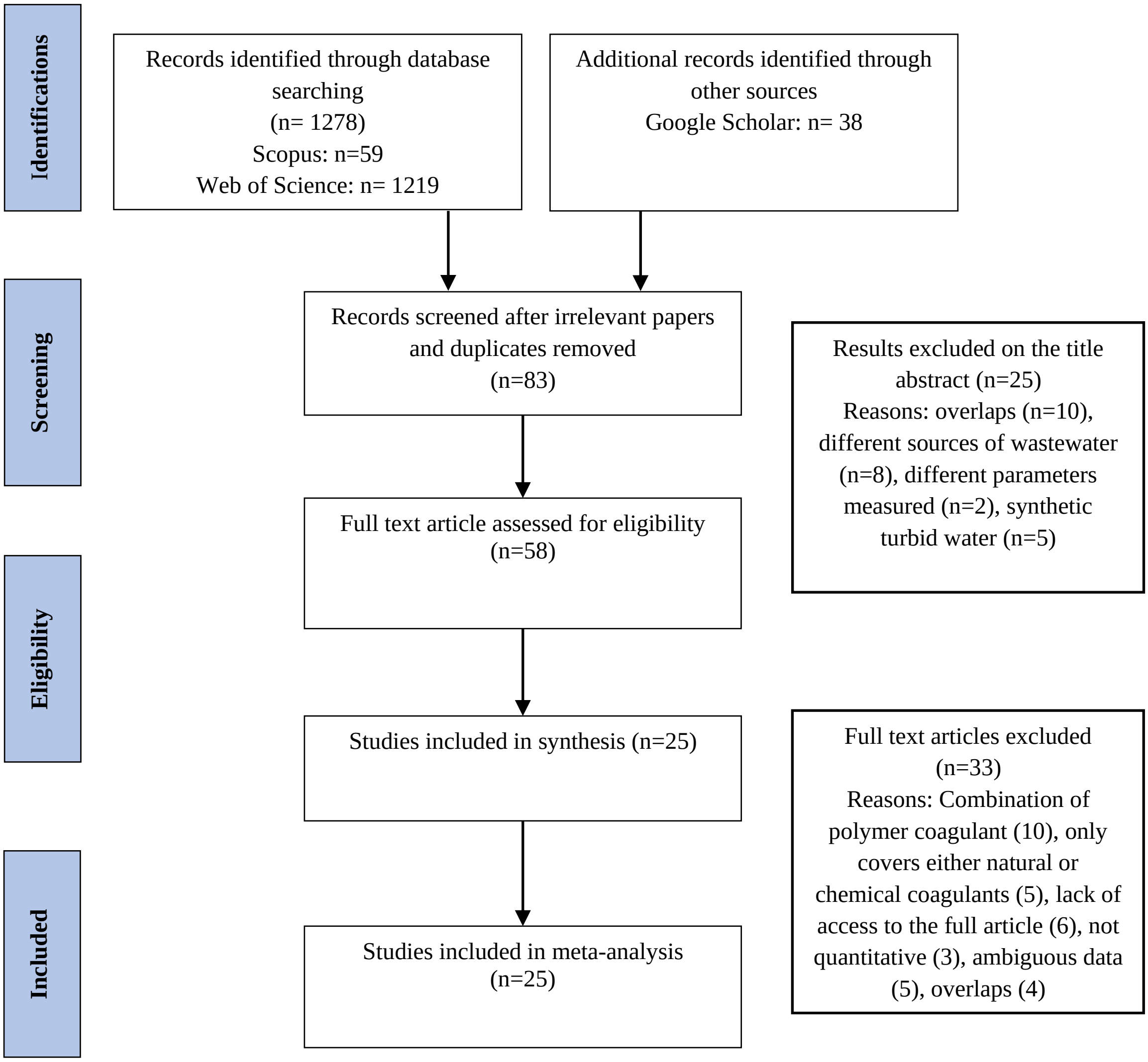

Figure 1. PRISMA of the Flow Diagram in the Systematic Review Process

2.4 Analytic Data Strategy

Based on these systematic review processes, the data analytic strategy used in this review study was a quantitative study. The 25 selected articles from different types of plant-based coagulants were used to analyze their findings for a more detailed study. This method was used to determine the appropriate or suitable theme and sub-theme by extracting the information from the reading process through the abstract before proceeding to the full article in depth to obtain relevant studies. The quantitative study was implemented in the systematic review process because it related to the evidence to support the study for relevant results. Only experimental studies that test both plant-based and chemical coagulants were chosen to proceed with meta-analysis to validate the efficiency of the plant-based coagulant in removing turbidity and COD.

2.5 Meta-analyses

The meta-analysis was used in this study to systematically assess the studies using Cochrane Review Manager (RevMan) 5.4 software. Data extracted from articles to carry out the meta-analysis were the percentage removal and standard deviation. As a result, the mean difference (MD) was used to determine the removal percentage difference between plant-based coagulants and chemical coagulants (Andrade, 2020a; Wang et al., 2017). In this analysis, heterogeneity is measured to assess the variability and manifest the consistency among the studies. For this, Chi^2 with probability ($p < 0.05$) and percentage of variance (I^2) values were used. Note that significant probability ($P < 0.05$) may be present in the result, but it does not indicate the absence of heterogeneity. Thus, the percentage of variance, $I^{2,}$ is used as an additional method to assess heterogeneity. Normally, a value of more than 75% is considered high heterogeneity (Andrade, 2020b; Borenstein et al., 2010). Results are expressed as a mean difference for continuous outcomes with a 95 % confidence interval. Random effect model and forest plot were used to analyze the results. This analysis is important to statistically measure the strength to recommend the most efficient approach to remove impurities in industrial wastewater. Forest plots were used for visual interpretation and were generated to evaluate the strength of plant-based coagulants in removing COD and turbidity in industrial wastewater (paper, dairy, and textile wastewater). The graph was plotted and presented numerically with the representation of a diamond over a horizontal line. The diamond to the left indicates that the selected study favors the intervention group (a natural coagulant), while those to the right favor the control group (chemical group). The line of study that touches the null effect indicates the study was not significant towards both groups.

3. Results and Discussion

For the meta-analysis study, turbidity and COD data were collected from 7 articles on paper industrial wastewater and seven articles on industrial dairy wastewater. Finally, for textile industrial wastewater, 11 articles were referred to as tabulated in Table 2 which shows the summary of the articles finding.

Table 2. Summary of Articles Finding.

Industry	Plant-based coagulant	Chemical coagulant	Method of removal	Reference
	Moringa oleifera	Aluminum sulfate	Coagulation-flocculation	Boulaadjoul et al., (2018)
	Moringa oleifera	Aluminum sulfate	Coagulation-flocculation	Chum, (2020)
	Plantago major L.	Aluminum sulfate	Coagulation-flocculation	Mahmoudabadi et al., (2018)
Paper	*Ocimum basilicum*	Aluminum sulfate	Coagulation-flocculation, hybrid treatment	Mosaddeghi et al., (2020)
	Guar gum	Aluminum sulfate	Coagulation-flocculation	Mukherjee et al., (2014)
	Dolichas lablab, Azadirachta Indica, Moringa Oleifera, Hibiscus Rosa Sinensis	Aluminum sulfate	Coagulation-flocculation	Saravanan et al., (2017)
	Cassia obtusifolia	Aluminum sulfate	Coagulation-flocculation	Subramonian et al., (2014)
	Orange peel and Neem leaf powder	Aluminum sulfate	Coagulation-flocculation	Anju & Mophin-Kani, (2016)
	Moringa olifera	Aluminum sulfate	Coagulation-flocculation	Agrawal et al., (2019)

Industry	Plant-based coagulant	Chemical coagulant	Method of removal	Reference
Dairy	*Acacia mearnsii (TANAC)*	Polyaluminium Chloride (PAC),	Coagulation-flocculation, hybrid treatment	Dela Justina et al., (2018)
	Moringa Oleifera	Aluminum sulfate	Coagulation-flocculation, hybrid treatment	Elemile et al., (2021)
	Modified Tannin (Tanfloc POP)	Polyacrylamide (PAM)	Coagulation-flocculation	Muniz et al., (2021)
	Guazuma ulmifolia		Coagulation-flocculation/dissolved air flotation Chemical	Muniz et al., (2020)
	Tanfloc SG (Tanac)	Polyacrylamide (PAM)	Coagulation-flocculation/dissolved air flotation hybrid treatment	Pereira et al., (2020)
Textile	*Aloe steudneri gel*	Polyacrylamide (PAM)	Coagulation-flocculation	Adugna & Gebresilasie, (2018)
	Chayote (Sechium edule SW	Ferric chloride	Coagulation-flocculation	Almeida et al., (2017)
	Gossypium herbaceum	polyaniline coagulants	Coagulation-flocculation	Arulmathi et al., (2019)
	Moroccan cactus	Lime, Ferric chloride, and Aluminum sulfate	Coagulation-flocculation	Bouaouine et al., (2017)
	Moringa oleifera	Aluminium sulphate	Coagulation-flocculation	Fagundes-klen & Dotto, (2019)
	okra mucilage (Abelmoschus esculentus)	Chloride ferric	Coagulation-flocculation	Freitas et al., (2015)
	Strychnos potatorum (nirmali seeds), Eirchorrnia crassipes (water hyacinth)	Aluminium sulphate	Coagulation-flocculation	Prabhakaran et al., (2020)
	Tamarind seed powder, Chitosan, and Xanthum gum	Ferric chloride, Ferrous sulphate, Aluminiumsulphate, Poly aluminium chloride (PAC)	Coagulation-flocculation	Rana & Suresh, (2017)
	Ocimum basilicum L. (basil)	Aluminium sulphate	Coagulation-flocculation, hybrid treatment	Shamsnejati et al., (2015)
	Banana barks from Plantain plant (*Musa sapientum)*	$FeSO4$, $FeCl3$, Aluminium sulphate	Coagulation-flocculation, hybrid treatment	Shrivastava & Singh, (2021)
	Opuntia stricta (O. stricta),	Aluminium sulphate	Coagulation-flocculation	Hussain & Haydar, (2021)

3.1 Meta-analysis on the Turbidity Removal

Two subgroups were divided according to the studied parameters, which are the percentage of removal efficiency in turbidity and COD, as shown in Figure 2. The overall effect for each subgroup shows that analysis favoring natural coagulant and data has not significantly different among the three wastewaters (P>0.05). Briefly, in the paper industry, 4 out of 7 studies are statistically significant to the research, which does not overlap the null line (0); thus, drag the diamond favors the intervention group, which is good removal in natural coagulant. Meanwhile, 6 out of 7 studies for the dairy industry were statistically significant, and for the textile industry, three studies were statistically significant. Based on Table 3, turbidity in the paper industry is statistically significantly removed by natural coagulants (MD: -5.22%, 95% CI: -7.94, -2.50, P: 0.0002). However, turbidity removal has a similar effect in both coagulants for the dairy and textile industry due to the p-value (P>0.05) with dairy and textile industry wastewater favoring natural chemical coagulant with a mean difference of 0.42 % (95 % CI:-2.36, 3.19, P: 0.77) and 0.37 % (95% CI: -3.29, 4.04, P:0.84) respectively.

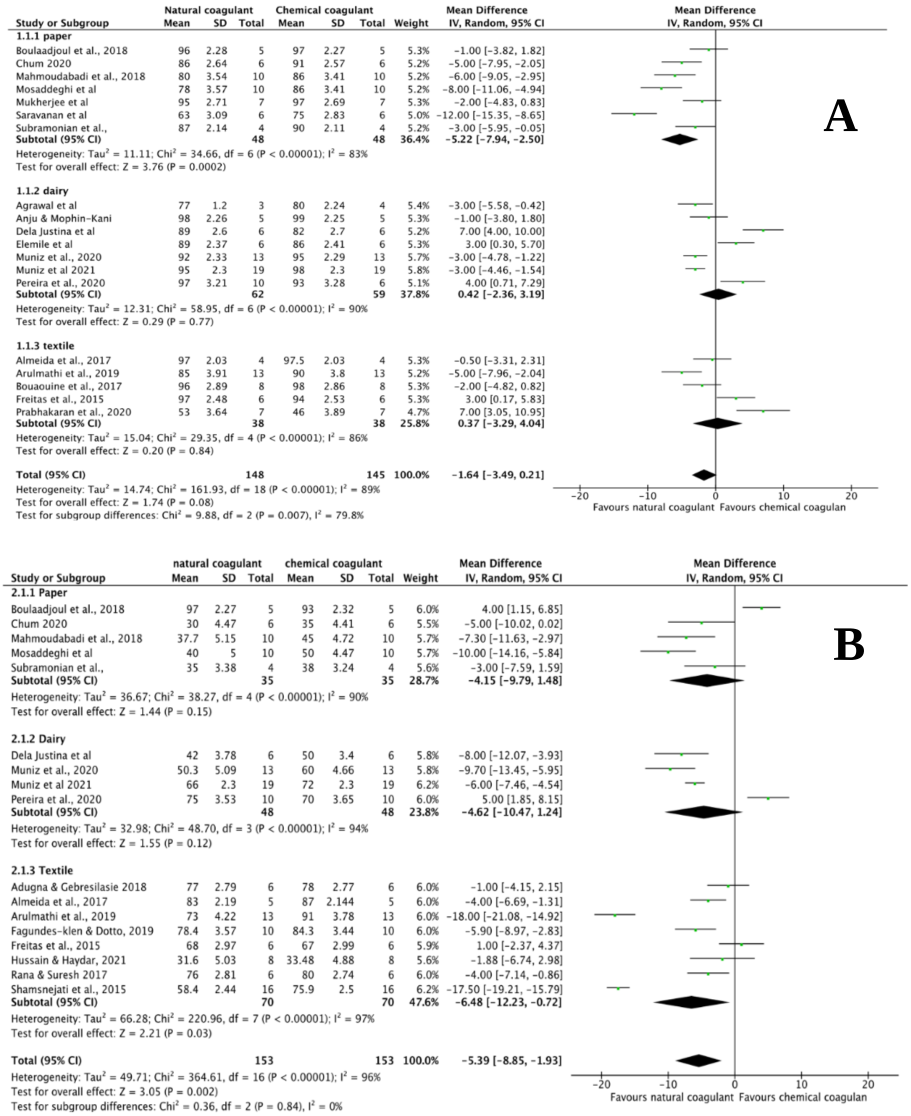

Figure 2. Percentage of Removal Efficiency in Turbidity and COD

Figure 2 show the random-effect model forest plot of percentage removal with a mean difference (MD) of (A) turbidity and (B) COD using a natural coagulant and chemical coagulant in the paper industry, dairy industry, and textile industry. Noted that natural coagulant in the forest plot refers to a plant-based coagulant. A negative value of MD indicates good removal in natural coagulants.

Table 3. Summary of Meta-analysis Findings.

Parameter	**COD MD % (95% CI)**	**Turbidity MD % (95% CI)**
Paper	-4.15 (-9.79, 1.48)	-5.22 (-7.94, -2.50)
Dairy	-4.62 (-10.47, 1.24)	0.42 (-2.36, 3.19)
Textile	-6.48(-12.23, -0.72)	0.37 (-3.29, 4.04)
Overall Effect	-5.39 (-8.85, -1.93)	-1.64 (-3.49, 0.21)

It can be suggested that hybrid treatment between chemical and natural coagulants is beneficial for removing turbidity, particularly in dairy and paper wastewater. Elemile et al., (2021) reported in the study that alum, *M. oleifera*, and blends alum and *M. oleifera* to reduce the initial turbidity of dairy wastewater reduced to 131 NTU, 102 NTU, and 102 NTU, respectively. The maximum removal efficiency of the turbidity subgroup was achieved by the blend of alum and *moringa oleifera* with 89.81% at a 10 ml dosage, which indicated that the comparison of between two subgroups reported a high removal rate in terms of turbidity. However, the turbidity removal rate by natural coagulant showed a significant effect of 93% in textile wastewater by a minimal dosage of 1.3 g/l, while the optimal dosage by aluminum sulfate is at three g/l with a removal efficiency of 98% to reduce turbidity (Bouaouine et al., 2017). It was reported that high turbidity removal efficiency in paper wastewater was achieved by using *M. oleifera* with 96%, which is equivalent to the alum that yields a removal efficiency of 97% (Boulaadjoul et al., 2018). Mahmoudabadi et al., (2018) in the study reported that the maximum turbidity removal efficiency achieved by *Plantago major L.* seed extract, which originates from plants because it can form flocs and has higher resistance, while chemical coagulants such as alum consisted of a single molecule that tends to attach with pollutants while natural coagulant attaches pollutants with their long polymeric chain. The mechanisms of plant-based coagulants can be in the form of dry cladodes, powder, or juice of fresh coagulants, which act on the process of wastewater treatment and contribute to the removal of pollutants from wastewater (Ferraz et al., 2017).

3.2 Meta-analysis on Chemical Oxygen Demand

According to Figure 2 and Table 3, there are significant differences among subgroups removing COD for all wastewater studied, which is shown by the p-value ($P < 0.05$). Briefly, 4 out of 5 studies in paper wastewater showed statistically significant differences as the studies did not overlap the line of null effect (0). Meanwhile, all studies showed statistical significance for dairy wastewater, but only five studies were significantly different in textile wastewater. Despite the insignificant different effect for each wastewater, meta-analysis shows overall effect across studies favors natural coagulants with MD of -4.15 %, -4.62 %, and -6.46 % for paper, dairy, and textile wastewater, respectively. Overall, COD is best removed by natural coagulants in textile wastewater but both natural and chemical coagulants in paper and dairy wastewater. Moreover, it indicates that either using chemical or natural coagulant, there is a 95% chance of having similar COD removal efficiency. As stated in the study by Adugna & Gebresilasie, (2018), the removal efficiency of *Aloe steudneri* gel with 77% compared to polyacrylamide at 78% and can be substituted to chemical coagulant since there are no significant differences for both coagulants but yet less negative effect to ecosystem. Several factors, such as sample size, variance, and reliability of the outcome, can contribute to the effect estimate of the pooled studies which the effect size varies among the studies (Israel & Richter, 2011).

Wastewater from the dairy industry is one of the most polluted industries in terms of its characteristics and the huge volume of wastewater generated. Other than that, the dairy industry is characterized in many countries as the main source of waste in food processing (Elemile et al., 2021). There are numerous processes involved in the marketing and manufacturing of dairy products, particularly in the dairy industry. A huge amount of waste is created from numerous operations in dairy production. The biodegradable components in the effluents are available in their natural condition in the milk or a damaged condition owing to additional processing (Shoba et al., 2015). The characteristics of industrial wastewater are determined by the characteristics of the product and the processing capabilities of the plant. It contains several disinfecting materials, which depend on the scrubbing method. Dairy effluents are classified based on high biochemical oxygen demand (BOD) and concentration of chemical oxygen demand (COD). One method of treating dairy waste is to adjust the pH with commonly used chemical coagulants. In general, additional chemicals produce de-emulsification, precipitation, coagulation, and flocculation. However, the usage of chemical coagulants results in a negative ecosystem and toxic sludge. Natural coagulants are a good alternative to dairy waste because they have the same properties as chemical coagulants while being more environmentally friendly. Okra can be seen as effective in the chemical oxygen demand subgroup by 67%, while the removal efficiency achieved by alum was 59% in dairy wastewater. Significant removal of COD achieved by okra coagulant compared to alum in dairy wastewater (Balamurugan & Shunmugapriya, 2019). Another study by Chonde & Raut, (2017) stated that *M. oleifera* seeds had similar coagulation properties to conventional coagulants such as alum which indicated that natural coagulants could be another approach to reducing the drawbacks of conventional coagulants towards the ecosystem. The COD removal efficiency of *M.oleifera* is high, which shows 75.6%, with minimal drawbacks to the ecosystem compared to conventional coagulants (Fagundes-klen & Dotto, 2019).

3.3 Heterogeneity analysis

The I^2 shows high heterogeneity with more than 80% for all industrial wastewater and is consistent with the random effect methods. The extent of heterogeneity can be evaluated by evaluating the study variance because the interpretation is specific to the study group (Higgins & Thompson, 2002). Heterogeneity in the study analysis is usually expected in the meta-analysis when the collected studies are analyzed by different subgroups and different methods. The high heterogeneity across studies for both turbidity and COD might be due to the different dosage, pH, and biological properties of each coagulant used. Mahmoudabadi et al. (2018) observed that the dosage of coagulant could be categorized as one of the important parameters to observe the coagulation and flocculation process since improper coagulant dosage can bring effects such as malfunction in flocculation. The performance of turbidity and chemical oxygen demand (COD) in the study reduced when the coagulant dosage increased. As shown in his findings, the optimum dosage of the coagulant was 0.1 g/L which results in maximum efficiency of turbidity and COD with the usage of *Plantago major* L Seed extract as a coagulant (Mahmoudabadi et al., 2018). Another study by Boulaadjoul et al. (2018) using *Moringa oleifera* reported that the optimum coagulant dosage was 150 mg/L for the removal of turbidity in the paper mill industry effluent. The capability of *Moringa oleifera* can be observed as the turbidity removal efficiency reached 96.02% using 150 mg/L dosage compared to the optimum turbidity rate for maximum turbidity removal of alum, which was reached 99.53% with 300 mg/L dosage. Other than that, the addition of coagulant dosage increased the aggregation among the particles; thus, it is important to identify the optimum coagulant to reduce the sludge volume and cost after the wastewater treatment process, especially industrial wastewater. The characteristic of *Cassia obtusifolia* seed gum had been observed in the raw pulp and paper mill industry, where it showed that the optimal dosage obtained was 0.75 g/L (Subramonian et al., 2014). In addition, the optimum COD removal efficiency by *Moringa oleifera* was obtained by 97.28% with 150 mg/L dosage, while 93.3% was observed at 300 mg/L by alum, where it can be concluded that *M. oleifera* seed powder proven to be a suitable initiative to improve the wastewater treatment of paper wastewater treatment.

The summary for the forest plot for the combination of the included studies indicated all the individual studies were homogeneous, and there is a presence of high heterogeneity in these studies. It also strengthens the hypothesis that natural coagulant is favorable in removing turbidity and COD in textile wastewater (MD: -2.10, 95% CI: -4.83, 0.64, P:0.13), although both coagulants show equivalent removal efficiency. Natural coagulants can be seen as a potential substitute for chemical coagulants as they provide equal removal efficiencies with conventional coagulants. The overall effect may be statistically significant even if the intervals of confidence of some of the individual studies cross the vertical line indicating no effect. This suggests that the meta-analysis controls the statistical power of multiple studies to estimate the total impact more precisely than that of any one research, which is shown graphically by the smaller confidence interval, CI of the pooled estimate than each study (Viechtbauer, 2007). It was observed that factors investigated, such as pH and coagulant dosage (the value range), were found to bring an effect on the coagulation performance since some of the coagulants required lesser dosage compared to chemical coagulant such as alum, in achieving the maximum efficiency removal in wastewater.

4. Conclusion

Based on this systematic review, the performance of a plant-based coagulant (a natural coagulant) can be seen as equal to the performance of an alum. From meta-analysis, the effect of the intervention group (a natural coagulant) showed a significant effect on the study. Forest plots from the paper industry, dairy industry, and textile industry indicated that the intervention group stated statistically significant, which means it has strong evidence that all the included studies vary from each studies. Turbidity and COD from three selected industrial wastewater are best being removed by natural coagulant compared to chemical coagulant with an increase in removal percentage, which is shown by the mean difference in the forest plot with paper (-4.70 %) > textile (-2.10 %) > dairy (-1.19 %). As a recommendation for further research, a meta-analysis study on the method and parameters could be conducted to systematically identify the mechanism of natural coagulants in industrial wastewater. The finding might help researchers to consider natural coagulants to remove impurities in industrial effluent and support the need for further research into the development of sustainable coagulants for sustainable wastewater treatment processes in future use.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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