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Review article

A comprehensive review on the selection of plant's part as coagulant for water/wastewater treatment

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ABSTRACT

The use of plants as biocoagulants in water/wastewater treatment is currently emerging. This review article explores the potential of each plant's part functioning as a biocoagulant for pollutant removal. Bibliometric analysis was employed to analyze the development of research in natural and biocoagulants, while descriptive analysis was used to clearly juxtapose the performance of each plant's part in treating water/wastewater. Bibliometric findings reveal a high increment in the publication of natural coagulants in the year 2016. The keywords of flocculation, pH, turbidity, and water purification are mentioned to be the closest node related to the coagulation. Comparison between plant parts showed that research on seeds is dominating the previous literature (26.31 %), followed by leaves (10.89 %) and peels (5.75 %). Overall performance analysis showed that plant biocoagulants are superior in removing turbidity (median 83.45 %), while the performance of removing total suspended solids, chemical oxygen demand, and biological oxygen demand are also considerably good (mean 68.38 %, 71.36 %, 67.16 %, respectively). The seeds and other parts of the plants showed the highest removal of turbidity among other parts (mean of removal 90 % and median >90 %). Other parts of the plants are composed mostly of plant extracts, including mucilage (18.47 %), gum (9.67 %), starch (8.36 %), etc. (10.37 %). Overall, the effectiveness of plant biocoagulants in removing pollutants varies compared to that of commercially available coagulants. The current development of biocoagulants indicates that research is currently in the integration and hybridization stage. Future approaches are suggested to focus on upscaling the treatment to an industrial scale, simplifying the extraction procedures, and conducting species-specific analysis to enhance and polish the current knowledge of plant bicocoagulants in water/wastewater treatment.

1. Introduction

In removing suspended particles from water and wastewater, settling methods become inadequate when the suspension contains fine/ultrafine and colloidal particles [94]. In that case, coagulation and flocculation are one of the main treatments often used in water and wastewater treatment to remove suspended particles [22]. Chemical coagulants, such as ferric/ferrous ($FeCl_3$, $FeCl_2$, $FeSO_4$) and aluminum salts ($Al_2(SO_4)_3$, $AlCl_3$), are often used because they are effective in aggregating suspended and colloidal particles [65]. However, the residue generated from the process is non-biodegradable, which requires further treatment [49]. On the other hand, aluminum is reported to have an important role as a mediator in Alzheimer's disease [104]. Therefore, a bio-based coagulant is recommended as an alternative to reduce the

Abbreviations: BOD, Biological oxygen demand; COD, Chemical oxygen demand; G, Velocity gradient; g/L, gram per liter; mg/L, milligram per liter; pH, potential of hydrogen; RM, Rapid mixing; rpm, Rotation per minute; SM, Slow mixing; ST, Sedimentation time; TSS, Total suspended solids.

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negative impact of the process.

Currently, biocoagulants produced from animals, plants, and microorganisms have been promising to replace chemical coagulants in water and wastewater treatment because of their ability to remove suspended solids, organic compounds, and turbidity with high efficiency [47]. However, biocoagulants extracted from plants are most investigated due to their abundance, and the resulting residues are biodegradable [83]. Previous literature reported that plant-extracted coagulants contain proteins and carbohydrates that have the potential to act as active compounds in the aggregation process of suspended particulates and colloids through mechanisms such as charge neutralization, bridging, and adsorption [7,15].

Some researchers reported that all parts of the plant, including seeds, leaves, stems, and peels, can be extracted and potentially used as a biocoagulant, such as research from Ahmed et al. [8], where biocoagulants extracted from *Moringa oleifera* leaves can reduce TSS, BOD, and COD by >70 % from domestic wastewater. On the other hand, Getahun et al. [36] reported that biocoagulants extracted from *Moringa stenopetala* seeds were also able to remove turbidity and color of wet coffee processing wastewater by >95 %. Dharsana and Prakash [27] also reported that biocoagulant from banana peel was also able to reduce the turbidity of river water by 83 %. It was indicated that every part of the plant has potential as a biocoagulant.

Many review articles have reported the potential of plants as biocoagulants. Most of them only focus on the ability to remove pollutants in general, the extraction methods, and the removal mechanisms. However, deeper discussions related to which plant parts have the most potential as biocoagulants are minimal and only found in research articles within their discussions. Therefore, to fill the gap, this review paper aims to investigate which plant parts have the most potential to be used as biocoagulants to treat water or wastewater. This review summarizes and compares the performance of each part of the plants from previously published literature in removing pollutants. On the other hand, the current development of plant biocoagulant is also discussed. In the end, future approaches and recommendations for research are also presented in this paper.

2. Materials and methods

2.1. Data identification and determination criteria

This comprehensive review has three main analyses to answer the questions: (i) What is the current status of plant-based coagulant application for water and wastewater treatment in the world? (ii) What parts of plants are used the most for biocoagulant? (iii) How does the selection of the plant's part as a coagulant affect the overall performance in water and wastewater treatment? This article used the hypothesis that a specific plant's part is being used as a coagulant over the other parts and that the appropriate selection of the plant's part affects the overall plant-based coagulant's performance. To answer the main questions, this study employs VOS viewers to assess the co-occurrence of the related keywords and terms used in the last 15 years [80]. PRISMA 2020 was used as a basic methodology in the identification, determination, and analysis of the literature used to construct research novelty [42].

In the identification stage, the SCOPUS database was used as the main population [52,73]. Article metadata was extracted on 1–25 March 2025. The search criteria of "bio coagulant" or "natural coagulant" were used to assess the number of publications for the last 15 years. A number of papers were exported as a .csv file, which was then used to generate a graph of the number of publications over time. In the determination stage, additional criteria of (i) Abstract, title, or keywords containing "plant" word; (ii) Manuscript mentions the utilization of specific plant's part as coagulant; (iii) English is the main language of the manuscript; (iv) Paper are published between 2010 and 2025 (Past 15 years); were included to attain focused discussion. In this stage, the first and second authors (SBK and MFI) were responsible for determining the used literature based on the given constraint for further analysis.

2.2. Data analysis

The selected paper's metadata was exported from the SCOPUS database as a .ris file. VOS viewer was then used to construct keyword and term co-occurrence maps [58]. Minimum co-occurrence was set to 20, with full counting set for keyword co-occurrence and binary counting set for term co-occurrence analyses [105]. Overlap maps were generated for both of the co-occurrence maps [87].

In the analysis stage, qualitative content analysis was used to describe the generated co-occurrence maps to clearly show the current status of plant-based coagulant utilization in water and wastewater treatment [19]. Descriptive cluster and link correlation analyses were used to explain the co-occurrence maps qualitatively [103]. To analyze the distribution of the plant's part used as a coagulant, obtained data was then refined by applying further search criteria of (i) Seeds or seed, (ii) Leaf or leaves, (iii) Shell or shells or pod or pods, (iv) Stem or stems; and (v) Flower or flowers; which then later be used to categorize the findings. The selected plant parts are obtained based on the previous literature study.

Further analysis was carried out by using a comparative method to juxtapose the different plant parts' performance as coagulants [91]. Descriptive analysis was then used to provide current development and future research approaches [101]. The conclusion was then structured to answer all the above-mentioned questions based on the obtained findings.

3. Results and discussions

3.1. Bibliometric findings on the development of biocoagulant research

The selected criteria of "bio coagulant" resulted in 436 documents (336 research, 41 reviews, and 59 others), while the criteria of "natural coagulant" resulted in 2385 documents (1802 research, 174 reviews, and 409 others) for the past 15 years. The number of publications per annum for the last 15 years is illustrated in Fig. 1.

Fig. 1 shows that research on "bio coagulant" and "natural coagulant" is gaining interest over the past 15 years. A high increment of publication in both keywords appears from 2015 onwards, suggesting the rise of eco-friendly coagulants for water treatment. In terms of keyword selection, natural coagulant is far more used as compared to the bio coagulant. After refinement by applying "plant" search criteria for both "bio coagulant" and "natural coagulant" the total document was reduced to 523 articles in the last 15 years, concluding that approximately 25 % of the paper included in the identification phase discussing plant-based coagulant. The keyword and term co-occurrence maps produced using the selected 523 articles metadata are presented in Fig. 2.

Based on the keyword co-occurrence map (Fig. 2a), coagulation is the main link among other keywords (most occurring keywords in the dataset). "Flocculation," "pH," "turbidity," and "water purification" are mentioned to be the closest node to the main link, suggesting that coagulation is highly related to flocculation, while pH and turbidity were the most analyzed parameter for water purification. "Plant extract," "natural coagulant," "*Moringa oleifera*," and "wastewater treatment" are mentioned to be the raising topic on this link. Referring to the plant-based coagulant, keywords of "seed," "seeds," "plant extract," "plant extracts," and "*Moringa oleifera*" appeared to have high co-occurrence among the selected articles (co-occurrence > 20) [105]. This result may suggest that the seed is the most utilized part of the plant as a coagulant. In addition, plant extract (unspecified) is also mentioned by most of the researchers discussing the plant-based coagulant.

Further analysis of the term co-occurrence map (Fig. 2b) revealed that the keywords of "natural organic matter," "water treatment plant," "coagulation," "ferric chloride," "poly aluminum chloride," and

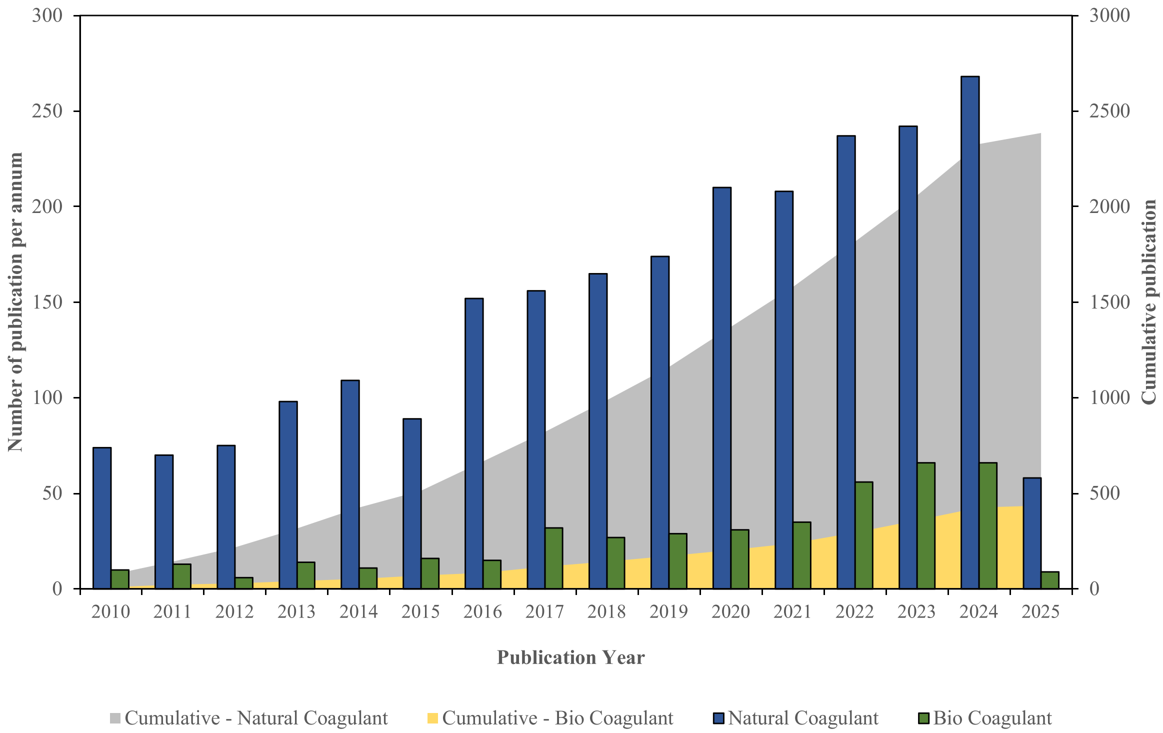

Fig. 1. Number of publications on “natural coagulant” and “bio coagulant” indexed by SCOPUS for the last 15 years.

"sedimentation" appeared to be established term among the selected articles. The keywords “natural coagulant,” “*Moringa oleifera*,” “seeds,” and “wastewater treatment” are among the currently emerging terms, suggesting an increasing interest in eco-friendly coagulants for wastewater treatment. The appearance of “*M. oleifera,*” “*Moringa oleifera* seed,” “*Moringa oleifera,*” and “seed” in the co-occurrence link emphasizes that seed is the most used plant’s part as coagulant based on the bibliometric finding. Besides the plant’s part, plant extract was also highlighted in the term co-occurrence map as “tannin” showed 24 co-occurrences, and “protein” showed 55 co-occurrences among the selected articles. Additionally, *M. oleifera was* revealed as one of the most used plant species to be used as a coagulant. Based on the term co-occurrence map, the plant-based coagulant is also highly related to the removal of turbidity, chemical oxygen demand, suspended solids, and natural organic matter.

3.2. *Selection of plant’s part based on literature*

After applying the further criteria for plant’s part composition, seed dominated the research by 26.31 %, followed by leaf (10.89 %), peel (5.75 %), and stem 5.66 % as depicted in Fig. 3. Based on the composition, the “other parts” part comprises up to 46.86 % of the total articles. The majority of these “other parts” articles dealt with the plant extracts, as previously highlighted in Fig. 2. Plant extracts, such as mucilage, gum, and starch, are mentioned to be contributed to the “other parts” with tannin [39], protein [11], and polysaccharides [33] were obtained from the purification of the plant but the corresponding extracted part was not specified or not mentioned in the title, abstract, and also keyword sections.

3.3. *Comparative performance of selected plant part as biocoagulant*

To enhance the given discussion on the plant’s part selection for biocoagulant, the performance of plant biocoagulant in treating several pollutant parameters is tabulated in Table 1. In accordance with Fig. 3, previous research also mentions much research about the utilization of seed parts as coagulants for water/wastewater treatment. In addition to that, *Moringa* sp. dominated the plant species used as a biocoagulant. *Moringa* sp., especially its seeds, is known to contain a rich amount of protein [51,86], which may function as a coagulating agent during the treatment process.

Based on the summarized data, most of the articles discuss the performance of biocoagulants in treating turbidity parameters, while some of them also mention the removal of color, total suspended solids (TSS), chemical oxygen demand (COD), and biological oxygen demand (BOD). Turbidity removal varies from 0 to 99.99 %, while it ranges between 1.2 to 99.24 % for TSS, from 14 to 99.89 % for COD, and from 14 % to 97.91 % for BOD. Plant biocoagulants also exhibit the potential to remove some metal ions, oil, and nutrients. For comparison, alum removed 63.03 % COD and 91.64 % color from industrial wastewater [79], 90 % turbidity from river water [69], 51.82 % TSS and 70.02 % COD from palm oil mill effluent [92], 99.08 % turbidity, 98.71 % TSS, 97.29 % color, and 75.31 % COD from aquaculture wastewater [6]. Table 1 is also represented as boxplot charts, as shown in Fig. 4 and Fig. 5.

Based on Fig. 4, it can be seen that the highest removal of turbidity is higher than the highest removal of TSS, COD, and BOD, as also observed for the mean and median of removals. Some values of extremely low outliers are observed for turbidity, TSS, and COD removals, which may be subjected to different operational parameters and biocoagulant types. From this finding, it can be concluded that plant biocoagulant showed an exceptional performance for turbidity removal. However, high variability of the obtained turbidity removal may suggest a further optimization is needed to obtain more stable removal values. The COD and BOD removal data are relatively more stable than turbidity. However, a lower mean and median value may be subjected to the contribution of plant biocoagulant itself to the organic matter, reducing the overall performance of organic removal from water/wastewater. Since turbidity removal data dominate the structure, further deeper analysis of the performance of each plant part is conducted based on the turbidity removal and summarized in Fig. 5.

Referring to Fig. 5, the highest turbidity removal is shown by the seed part, with the highest mean obtained by both seeds and other parts (90 %). In Fig. 5, data for turbidity removal by stem part is very limited (only one data); thus, whiskers analysis cannot be conducted on this

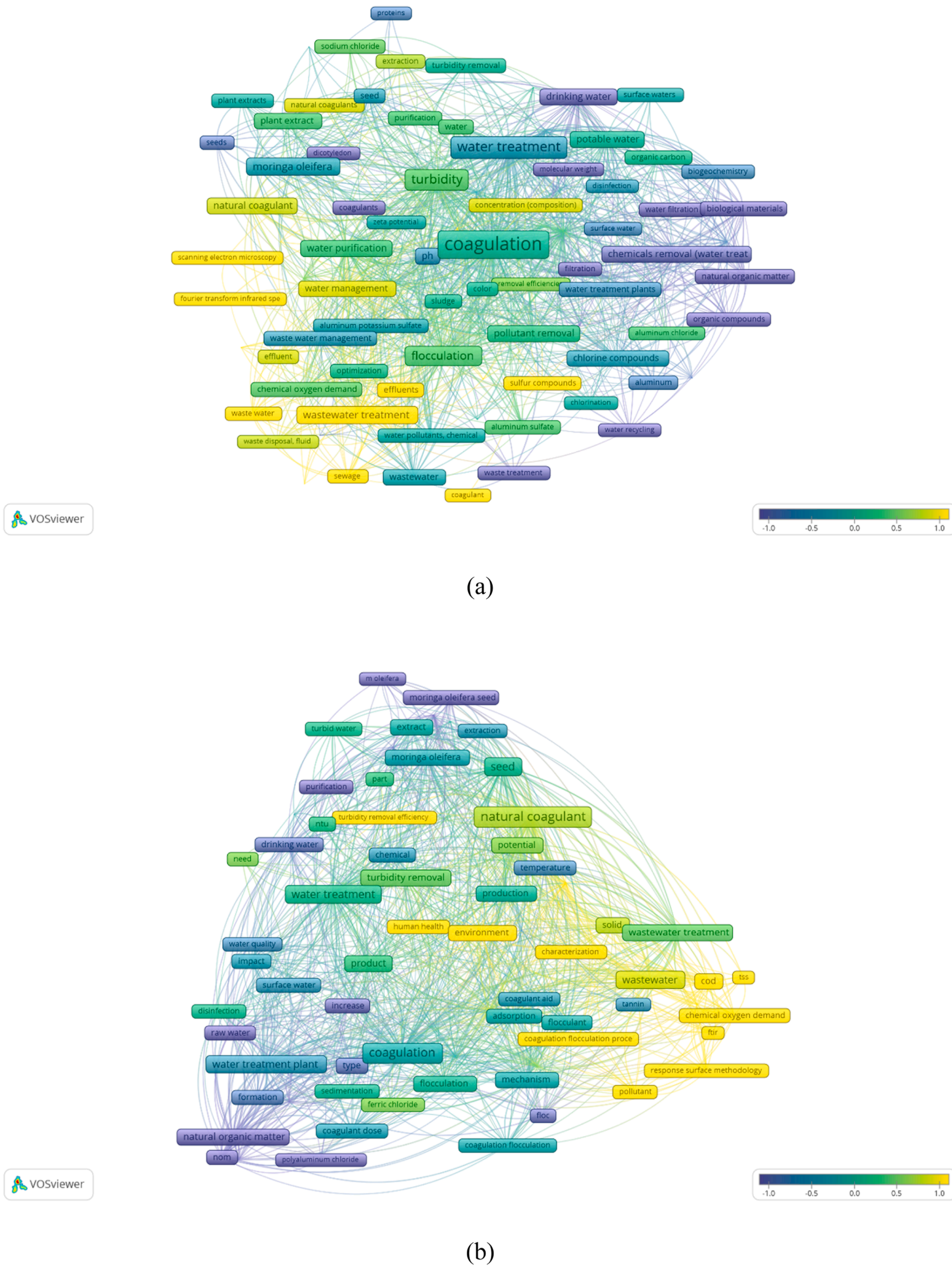

Fig. 2. (a) Keyword and (b) terms co-occurrence maps generated from the selected article metadata ($n = 523$).

part. The most consistently high turbidity removal is obtained by other parts, which shows the smallest removal range. However, some outliers can be seen to be far below the range. Even though seeds have a bigger range, and both seeds and other parts have the same mean, the median of the data is higher on other parts. This suggests that other parts of the plants (including mucilage, extract, etc.) performed more consistently in terms of turbidity removal. Other parts category includes the extract of some specific bioactive compounds, which may directly perform better as compared to a raw plant's part. Since the other parts plot have two outliers while seeds have no outliers, it can be said that the performance of both of these parts is similar.

Protein is mentioned as one of the most contributed extracts from plants part towards coagulation processes. It is a high molecular weight complex molecule including several cationic functional groups [93]. This compound enhances the coagulation process by providing positively charged functional groups or by facilitating interparticle bridging

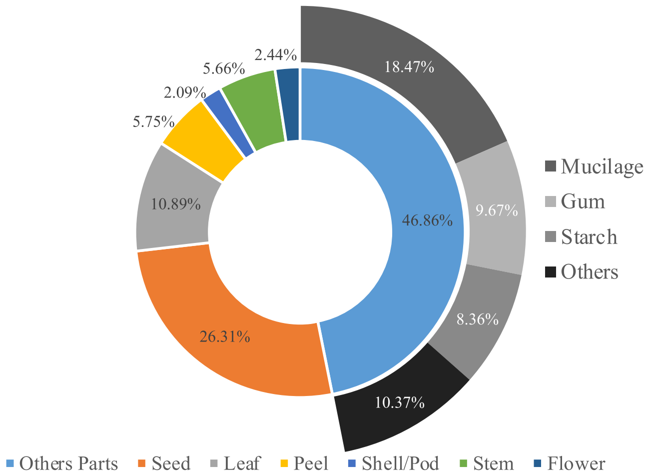

Fig. 3. Composition of plant's part used as coagulant from the refined article metadata (n = 523).

within the suspension [53]. Following the protein, polysaccharides are also mentioned to play crucial roles in the coagulation process by facilitating charge neutralization, interparticle bridging, and complexation [16,32].

Data of the flower part showed a tall bar with a very wide interquartile gap, low mean, and also low median. This was due to a significant difference in the turbidity removal performance by *Musa* sp. flower (>90 % efficiencies) and others (below 20 %). In general, flowers are seen to contain a minimum amount of compound that can function as a coagulant. However, there might be some specialties for *Musa* sp. species, which then become future opportunities to conduct species-specific research.

Since *M. oleifera* seems to be the most used species as a plant biocoagulant, while protein and polysaccharides were mentioned to play an important role in coagulation and flocculation processes, Table 2 is constructed based on the previous literature to analyze the composition of these compounds in each part of the plants.

Based on Table 2, the seeds of *M. oleifera* are high in protein content, which may be the basis for understanding why seeds are performing well as plant biocoagulants. The presence of cationic protein may assist the coagulation and flocculation processes by aiding the charge neutralization mechanism [10,98]. Leaves and peels of *M. oleifera* were also mentioned to be rich in carbohydrates, which may also assist the coagulation and flocculation processes via bridging mechanisms [24,60]. Contradict record is obtained for shells/pods part of *M. oleifera*, in which it shows low content of both protein and carbohydrate, yet it performed better than leaves and peels as plant biocoagulants (Fig. 5). Different plant species may pose different characteristics of their plants part [40,53], which make the performance of pollutant removal distinct. Similarly, the content of protein and carbohydrate in flower parts of *M. oleifera* is considerably high as compared to other parts, but the use of M. *oleifera*'s flower as plant biocoagulant is currently limited, and flower parts shows a very inconsistent performance of pollutant removal based on Fig. 5.

3.4. Current development and challenges of plant biocoagulant

Research on plant biocoagulants is not new and has already passed some development stages (Fig. 6). Fig. 6 depicts the progression of plant biocoagulants from conventional usage to contemporary hybrid applications. Plant biocoagulants were originally employed in ancient times for domestic purposes, highlighting their historical importance in water purification. As understanding advanced, their application broadened to small-scale industries, especially in food processing, where plant extracts functioned as natural coagulating agents. This initiated a research development phase, wherein plants were identified as feasible substitutes for synthetic coagulants in wastewater treatment, generating interest in their extensive environmental uses.

Subsequently, efforts were directed towards process improvement, concentrating on identifying critical aspects affecting the performance of plant biocoagulants, including dose, pH sensitivity, and many more. Currently, hybridization entails the amalgamation of plant-derived biocoagulants with other treatment methods, like wetlands for resource reclamation and nanocomposites for more sophisticated and advanced removal, to improve efficiency and sustainability. This advancement underscores a transition towards environmentally sustainable and innovative water treatment systems in accordance with sustainable development objectives.

Referring to Section 3.3, it is clear that plant variability significantly impacts the effectiveness of the plant biocoagulant in removing pollutants. Different plant species, and even variations from different sources within the same species, have shown distinct coagulation performances [3]. It may also be influenced by several factors, such as the plant's age and the season of collection. The differences in overall performance, even within the same species, result from the varying biochemical properties of the selected plant part used as a biocoagulant [74].

Some of the used plant parts as biocoagulant are actually edible and serve medicinal purposes, which raises the potential for competition with food and medicinal resources. For example, *M. oleifera* seeds are known as an antioxidant agent that is widely used in the supplement industry [37]. However, the shells of these plants are considered byproducts [20]. The use of banana and cassava peels also poses minimal potential food competition since waste is being used as plant biocoagulant materials [27,48]. Appropriate selection of the plant's part to be used as biocoagulant is a crucial step to avoid potential competition.

As also discussed by Ahmad et al. [7], there is currently no standardized procedure for the extraction of plant biocoagulant. There is no protocol for extracting specific species and their respective plant parts to achieve the best yield of bioactive compounds. The extraction of bioactive compounds has demonstrated relatively higher efficiency in pollutant removal due to the direct utilization of functional compounds as biocoagulant [4]. Given that the extraction of plant parts for use as biocoagulant is costly and time-consuming, selecting appropriate species may reduce the time and resources required, ultimately lowering extraction costs.

Currently, the average price of alum varies between 2 and 5.8 USD/kg [48,61], while the cost of dried plant biocoagulants is higher, estimated to be 3.3 USD/kg for cassava peels [48] and up to 52.3 USD/kg for okra shells [56]. Even though the cost of materials is relatively high, the operational cost of plant biocoagulant is estimated to be lower. The use of commercially available coagulants, such as alum and ferric chloride, generated sludge that contains metals (Al, Fe, etc.), which makes it harder for further utilization (especially using anaerobic digestion) and disposal [50,106]. The overall operational costs of coagulation and flocculation in wastewater treatment are calculated to be 1.5 USD/m^3 for alum, 1.5 USD/m^3 for *M. oleifera*, and 0.025 for USD/m^3 avocado seed extract [106]. A comprehensive techno-economic analysis of the capital and operational costs of using plant biocoagulant in coagulation-flocculation is currently still limited, which needs to be explored further.

3.5. Future approaches

The efficacy of plant-based coagulants in removing pollutants, particularly turbidity and suspended solids, is indisputable. Nonetheless, the majority of the documented investigations were performed at a laboratory scale, and the use of plant-based coagulants in a true industrial context remains constrained. One of the pilot-scale research used tannin derived from bark (*Acacia mearnsii*) and wood (*Schinopsis balansae*), revealing divergent results compared to the majority of laboratory-scale studies [39]. Multiple aspects must be taken into

Table 1
Performance of plant biocoagulant in treating water pollutants.

Plant species	Part	Operational condition*	Used for	Removal	Reference
Pine	Cones	Dose 50 mL/L pH 10 ST 30 min	Industrial wastewater	Zinc 98.82 % Copper 90.58 %	[13]
Pine	Cones	Dose 3 g/L pH 8.83 RM 200 rpm 5 min SM 90 rpm 15 min ST 60 min	Industrial wastewater	COD 76 %	[2]
Corn and potato	Extracts (starch)	RM 300 rpm 1 min SM 60 rpm 25 min	Artificial turbid wastewater	Turbidity 97.57 % Color 73.28 %	[76]
Cotton	Extracts	RM 200 rpm 1 min SM 60 rpm 3 min ST 30 min	Drinking water	Turbidity 90 %	[25]
Moringa oleifera	Extracts	RM 245 rpm 2 min SM 45 rpm 15 min	Steelworks wastewater	Oil 67 %	[57]
Palm petiole	Extracts (lignin)	Concentration 300–1000 mg/L RM 300 rpm 3 min SM 60 rpm 20 min ST 60 min	Artificial turbid and dye wastewater	Turbidity 98.2 %	[107]
Spirodela polyrhiza	Extracts	RM 200 rpm 1 min SM 10 rpm 30 min ST 60 min	Urban wastewater	COD 73.22 %	[75]
Ziziphus mauritiana	Extracts	RM 200 rpm 1 min SM 10 rpm 30 min ST 60 min	Urban wastewater	COD 82.48 %	[75]
Allamanda cathartica	Flower	–	Groundwater	Turbidity 0 % TSS 1.2 %	[26]
Calotropis Procera	Flower	RM 100 rpm 2 min SM 35 rpm 20 min ST 30 min	Artificial turbid wastewater	Turbidity 20 %	[77]
Hibiscus rosasinenensis	Flower	–	Groundwater	Turbidity 0 % TSS 5.6 %	[26]
Ixora coccinea	Flower	–	Groundwater	Turbidity 0 % TSS 12 %	[26]
Musa sp.	Flower	–	Iron ore wastewater	Turbidity 98.73 % TSS 99.24 %	[18]
Musa sp.	Flower	pH 6.25 Mixing speed 85 rpm	Iron ore wastewater	Turbidity 97.58 %	[97]
Aloe vera	Gum	Dose 0.8 mL/L pH 12	Artificial turbid wastewater	Turbidity 99.13 % TSS 94.0 %	[14]
Cassia obtusifolia	Gum	RM 150 rpm 5 min SM 50 rpm 25 min ST 5 min	Artificial turbid wastewater	TSS 86.9 % COD 36.2 %	[102]
Cassia obtusifolia	Gum	RM 150 rpm 5 min SM 10 rpm 15 min	Agro-industrial wastewater	TSS 93.92 % COD 61.15 %	[85]
Cassia obtusifolia	Gum	RM 150 rpm 5 min SM 10 rpm 15 min	Industrial wastewater	TSS 87.3 % COD 40.2 %	[88]
Cassia obtusifolia	Gum	RM 150 rpm 5 min SM 15 rpm 30 min ST 60 min	Agro-industrial wastewater	TSS 80 % COD 47 %	[84]
Fenugreek	Gum	RM 295 rpm 3 min SM 25 rpm 20 min	Arsenic-containing wastewater	As 90 %	[99]
Flaxseed	Gum	RM 295 rpm 3 min SM 25 rpm 20 min	Arsenic-containing wastewater	As 90 %	[99]
Sesbania	Gum	RM 150 rpm 1 min SM 30 rpm 15 min	Drinking water	Turbidity 98.3 %	[21]
Mangifera indica	Kernels	Dose 0.5 g/L Mixing 30 min ST 12 h	Artificial turbid wastewater	Turbidity 92.9 %	[71]
Azadirachta indica	Leaves	RM 180 rpm 5 min SM 50 rpm 15 min ST 30 min	Artificial turbid wastewater	Turbidity 67.2 %	[46]
Conocarpus lancifolius	Leaves	RM 180 rpm 5 min SM 50 rpm 15 min ST 30 min	Artificial turbid wastewater	Turbidity 75.5 %	[46]
Mixed neem, cassava, and wild betel	Leaves	Dose 0.79 mg/L RM 180 rpm 3 min SM 10 rpm 20 min ST 30 min	Aquaculture wastewater	Turbidity 85.17 % TSS 80.28 % Color 59.42 % COD 54.63 %	[6]
Moringa oleifera	Leaves	Dose 0.1 – 1.5 g/L RM 300 rpm 1 min SM 300 rpm 30 min ST 45 min	Domestic wastewater	Turbidity 53.7 % TSS 71.9 % COD 71.9 % BOD 71.47 %	[8]

(continued on next page)

Table 1 (*continued*)

Plant species	Part	Operational condition*	Used for	Removal	Reference
Neem	Leaves	Dose 0.31 mg/L RM 180 rpm 3 min SM 10 rpm 20 min ST 30 min	Aquaculture wastewater	Turbidity 82.7 % TSS 81.4 % Color 65.8 %	[5]
Piper sarmentosum	Leaves	Dose 2 g/L RM 300 rpm 5 min SM 180 rpm 30 min ST 30 min	Coffee processing wastewater	Turbidity 66.9 %	[83]
Trichanthera gigantea	Leaves	Dose 1.5 g/L RM 300 rpm 5 min SM 180 rpm 30 min ST 30 min	Coffee processing wastewater	Turbidity 63.3 %	[83]
Ziziphus spina-christi	Leaves	Dose 0.5 g/L	River water	COD 14 % BOD 32.42 %	[66]
Aloe vera	Mucilage	Dose 1.65 g/L pH 8.94 SM 70 rpm 19 min	Coffee processing wastewater	Turbidity 96.74 % Color 99.99 %	[36]
Aloe vera	Mucilage	Dose 1.65 g/L pH 8.94 SM 70 rpm 19 min	Coffee processing wastewater	COD 96.94 %	[35]
Austrocylindropuntia subulata	Mucilage	Dose 160 g/L RM 200 rpm 2 min SM 40 rpm 30 min	Artificial turbid wastewater	Turbidity 99 %	[64]
Cactus	Mucilage	RM 100 rpm 2 min SM 40 rpm 60 min	Textile wastewater	Turbidity 53.19 % TDS 97 % COD 25.37 %	[100]
Hylocereus undatus	Mucilage	RM 200 rpm 1 min SM 40 rpm 10 min ST 60 min	Dye wastewater	Turbidity 95 %	[55]
Lallemantia	Mucilage	RM 120 rpm 5 min SM 40 rpm 45 min ST 60 min	Saline oily wastewater	COD 87.35 %	[16]
Okra	Mucilage	RM 200 rpm 5 min SM 30 rpm 30 min	Palm oil mill effluent	TSS 88.19 % COD 30.56 %	[59]
Stenocereus griseus	Mucilage	RM 100 rpm 1 min SM 40 rpm 30 min ST 60 min	Domestic wastewater	Turbidity 67.24 % TSS 70.42 % Color 72.12 % COD 67.87 %	[29]
Artocarpus heterophyllus	Peels	RM 100 rpm 4 min SM 40 rpm 25 min ST 60 min	Artificial turbid wastewater	Turbidity 75 %	[78]
Banana	Peels	RM 200 rpm 2 min SM 20 rpm 10 min ST 30 min	River water	Turbidity 83 %	[27]
Cassava	Peels	Dose 500 mg/L RM 50–200 rpm 1–2 min SM 20–50 rpm 30 min ST 60 min	Domestic wastewater	Turbidity 77.04 % TSS 83.45 % COD 30.43 %	[48]
Guarana	Peels	RM 160 rpm 1 min SM 40 rpm 15 min ST 120 min	Domestic wastewater	Turbidity 88 %	[28]
Hylocereus undatus	Peels	RM 200 rpm 1 min SM 30 rpm 10 min	Dye wastewater	Turbidity 90 % TSS 70 % COD 20 %	[67]
Musa balsibiana	Peels	Dose 15 mL/L RM 200 rpm 5 min SM 40 rpm 10 min ST 15 min	Lake water	Turbidity 87.13 % TSS 82.15 %	[43]
Pomegranate	Peels	Dose 0.1 – 1.5 g/L RM 300 rpm 1 min SM 300 rpm 30 min ST 45 min	Domestic wastewater	Turbidity 85.18 % TSS 85 % COD 88.09 % BOD 97.91 %	[8]
Arachis hypogea	Seeds	Dose 15 mg/L SM 40 rpm 15 min ST 30 min	River water	Turbidity 75.4 % - 85.0 %	[9]
Avocado	Seeds	Dose 900 mg/L pH 9	Artificial turbid and dye wastewater	Turbidity 99.64 %	[106]
Cassia fistula	Seeds	Dose 0.6 g/L RM 200 rpm 5 min SM 20 rpm 5 min ST 30 min	Artificial Cu-containing wastewater	Copper 45.43 %	[23]
Cassia fistula	Seeds	Dose 12.3 g/L RM 200 rpm 5 min SM 20 rpm 5 min ST 30 min	Textile wastewater	Color 94 %	[68]

(*continued on next page*)

Table 1 (*continued*)

Plant species	Part	Operational condition*	Used for	Removal	Reference
Cyamopsis tetragonoloba	Seeds	RM 200 rpm 1 min SM 10 rpm 30 min ST 60 min	Domestic wastewater	COD 73.22 %	[75]
Date	Seeds	RM 200 rpm 15 min SM 60 rpm 30 min ST 60 min	Industrial wastewater	TSS 99 % COD 59.45 %	[1]
Grape	Seeds	SM 3 - 30 min ST 30 min – 24 h	Artificial Cr-containing wastewater	Cr 99.7 %	[30]
Moringa oleifera	Seeds	RM 200 rpm 3 min SM 45 rpm 30 min ST 60 min	Hospital wastewater	Turbidity 86.11 % COD 60.12 %	[70]
Moringa oleifera	Seeds	RM 226 rpm 3 min SM 90 rpm 4 min	Oil and grease containing wastewater	Oil 82.43 %	[62]
Moringa oleifera	Seeds	RM 200 rpm 3 min SM 45 rpm 30 min ST 60 min	Hospital wastewater	Turbidity 64 % COD 38.36 %	[70]
Moringa oleifera	Seeds	RM 200 rpm 3 min SM 45 rpm 30 min ST 60 min	River water	Turbidity 88.5 % Color 87.1 % TDS 92.1 % COD 52.6 %	[45]
Moringa stenopetala	Seeds	Dose 0.82 g/L pH 8.76 SM 73 rpm 28 min	Coffee processing wastewater	Turbidity 98.37 % Color 98.53 %	[36]
Moringa stenopetala	Seeds	Dose 0.82 g/L pH 8.76 SM 73 rpm 28 min	Coffee processing wastewater	COD 98 %	[35]
Olive	Seeds	RM 200 rpm 5 min SM 90 rpm 15 min ST 30 min	Industrial wastewater	TSS 99 % COD 86.3 %	[44]
Pinus halepensis	Seeds	Dose 3–12 mL/L pH 3–10 RM 200 rpm 3 min SM 110 rpm 30 min ST 40 min	Artificial dye wastewater	Color 86 %	[41]
Tamarindus indica	Seeds	Dose 0.6 g/L RM 200 rpm 5 min SM 20 rpm 5 min ST 30 min	Artificial Cu-containing wastewater	Copper 53.49 %	[23]
Trichosanthes cucumerina	Seeds	Initial turbidity 150 NTU G 708.9/s	Artificial turbid wastewater	Turbidity 99.5 %	[63]
Trigonella Foenum-Graecum	Seeds	pH 4.4–4.9 Mixing time 30 min	Palm oil mill effluent	Turbidity 94.97 % TSS 92.7 % COD 63.11 %	[54]
Vigna unguiculata	Seeds	Initial turbidity 150 NTU G 708.9/s	Artificial turbid wastewater	Turbidity 99.5 %	[63]
Watermelon	Seeds	1:4 seeds and alum ST 25 min	River water	TDS 98.26 % TSS 96.10 % COD 95.26 %	[31]
Castanea sativa	Shells	Concentration 10 mg/L pH 4–8 RM 150 rpm 1 min SM 20 rpm 3 min	Aquaculture wastewater	Turbidity 90 % Phosphorus 32 %	[95]
Crescentia cujete	Shells	Dose 1 g/L pH 7.12 RM 150 rpm 1 min SM 25 rpm 29 min	River water	Turbidity 84.3 %	[17]
Peanut	Shells	Dose 50 mg/L RM 250 rpm 30 s SM 30 rpm 15 min	Dairy wastewater	Turbidity 88.74 % Color 98.75 % COD 99.89 %	[96]
Peanut	Shells	RM 250 rpm 10 s SM 30 rpm 20 min ST 30 min	Dairy wastewater	Turbidity 93.66 % Color 56.98 %	[72]
Acanthus sennii	Stems	Dose 0.98 g/L pH 8.6 SM 76 rpm 21 min	Coffee processing wastewater	Turbidity 97.52 % Color 99.19 %	[36]
Acanthus sennii	Stems	Dose 0.98 g/L pH 8.6 SM 76 rpm 21 min	Coffee processing wastewater	COD 97.43 %	[35]

* RM: Rapid mixing, RPM: Rotation per minute, SM: Slow mixing, ST: Sedimentation time, G: Velocity gradient.

consideration before expanding the study to a larger scale, which becomes the current bottleneck. A laboratory-scale experiment is performed in a controlled setting utilizing a synthetic pollutant to demonstrate the desired performance in a certain parameter. Nevertheless, numerous factors are overlooked in laboratory studies, including the concentration of other pollutants [12], the interference of other pollutants/free ions [90], and the propensity for mechanisms to alter in the presence of inhibitors [70,82]. Some research mentioned the increasing of organic content by the use of plant biocoagulant [34]. This finding may also lead to an increase in biofouling potential if membrane

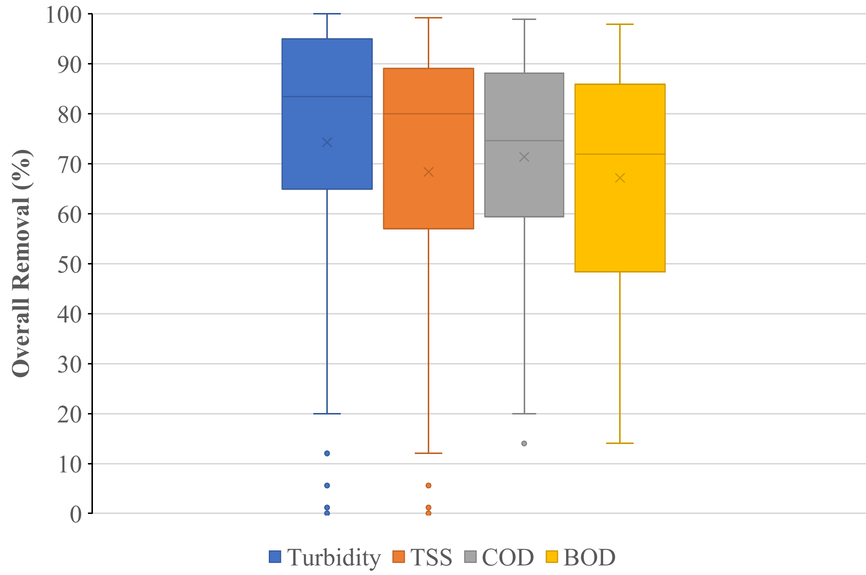

Fig. 4. Overall performance of plant biocoagulant in removing turbidity, TSS, BOD, and COD.

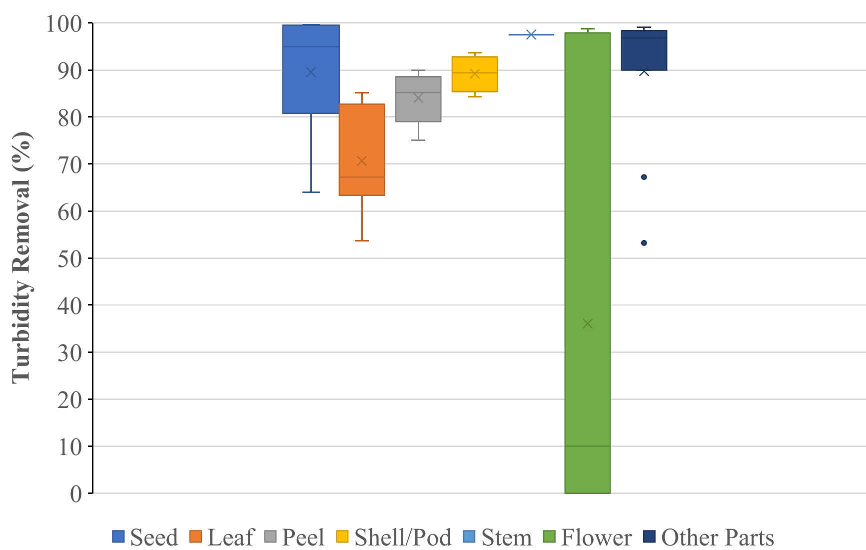

Fig. 5. Performance of each plant part in removing turbidity.

Table 2
Protein and carbohydrate contents in each part of *M. oleifera* (in mg/g dry weight).

Compound	Seed	Leaf	Peel	Shell/Pod	Stem	Flower
Protein	35.97[a]	29.4 [a]	12.15 [b]	2.5 [a]	8.69 [c]	14.94 [c]
Carbohydrate	8.67 [a]	41.2 [a]	34.8 [b]	3.7 [a]	26.93 [c]	57.88 [c]

[a] Data extracted from [38].
[b] Data extracted from [81].
[c] Data extracted from [40].

filtration is used as the integrated treatment [89]. Future approaches must account for the aspects above to provide unbiased results suitable for upscaling.

The existing extraction methods employed in coagulant processing represent a considerable deficiency since they are laborious and uneconomical due to the several phases required. The manufacture of plant-based biocoagulants involves collection, conditioning (including washing and drying), extraction, and purification. The preparation processes and optimal extraction methods of biocoagulants vary according to their sources. A standardized and optimal approach for the synthesis and processing of biocoagulants is becoming challenging [7]. Formulating methods for the production and processing of biocoagulants may address this specific issue. Protocols must have a flowchart delineating the selection of the best suitable approach depending on the parameters of the chosen plan. The protocol must also provide the optimal conditions for achieving the maximum production of biocoagulants, depending on the chosen pretreatment. The procedure may function as a guide and reference for the manufacture and processing of biocoagulants prior to their application in water or wastewater treatment.

Last but not least, conducting species-specific analysis on the performance of pollutant removal from water/wastewater is highly suggested as this paper reveals the most used parts of plants that function well as biocoagulant; future approaches need to account for the emerged concern on different species performance. As referring to the discussion of Fig. 5 before, different flower from different plant species exhibits significantly different turbidity removal performance. Currently, research that utilizes one species and analyzes each of the parts for

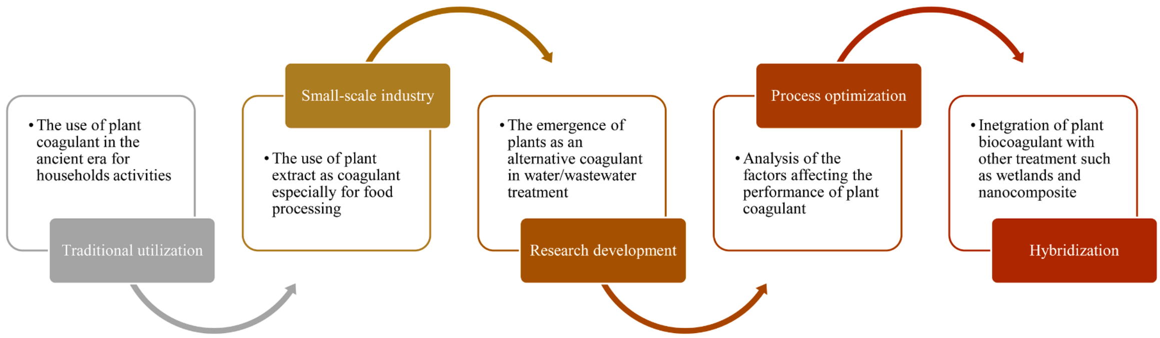

Fig. 6. Development of plant biocoagulant.

biocoagulant is not to be found. Compiling the performance of different plant parts of the same species from different literatures may also face some limitations due to the differences in environmental and operational factors. Future researches are suggested to deepen the species-specific analysis to obtain a clearer understanding of which part of plants functioned the best as biocoagulants.

4. Conclusion

Plants are increasingly being used as biocoagulants in the treatment of water and wastewater, with a high increment of publications related to natural coagulants in the year of 2016. Research on coagulation is highly related to the keywords of flocculation, pH, turbidity, and water purification based on the bibliometric findings. Research on the seeds part of the plant is dominating the prior literature, followed by leaves and peels. According to overall performance analysis, plant biocoagulants are superior at eliminating turbidity. The highest removal of turbidity was seen in the seeds and other parts of the plants, with a mean removal of 90 % and a median >90 %. To improve and refine the existing understanding of plant biocoagulants in water/wastewater treatment, future approaches are recommended to emphasize scaling up the treatment to industrial size, streamlining the extraction processes, and carrying out species-specific studies. This review also highlights the key limitations, such as plant variability and extraction inconsistencies, which could contribute to the standardization of extraction protocols and optimization of the plant's part functionalization as a biocoagulant.

CRediT authorship contribution statement

Setyo Budi Kurniawan: Writing – review & editing, Writing – original draft, Visualization, Data curation, Conceptualization. **Muhammad Fauzul Imron:** Writing – review & editing, Writing – original draft, Resources. **Azmi Ahmad:** Writing – original draft, Conceptualization. **Peer Mohamed Abdul:** Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

[1] S.S. Abu Amr, M.S.S. Abujazar, S.U. Karaağaç, R. Mahfud, M.Y.D. Alazaiza, R.J. A. Hamad, Application of plant-based natural coagulant for sustainable treatment of steel and iron industrial wastewater, Karabuk, Turkey, Desalin. Water Treat. 287 (2023) 39–45, https://doi.org/10.5004/dwt.2023.29393.
[2] M.S.S. Abujazar, S.U. Karaağaç, S.S. Abu Amr, S. Fatihah, M.J.K. Bashir, M.Y. D. Alazaiza, A. Yusof, M.M. Abou Auda, Factorial design and optimization of pinecone seed powder as a natural coagulant for organic and heavy metals removal from industrial wastewater, Desalin. Water Treat. 282 (2023) 107–117, https://doi.org/10.5004/dwt.2023.29199.
[3] V.T. Adeleke, N.E. Madlala, A.A. Adeniyi, D. Lokhat, Molecular interactions associated with coagulation of organic pollutants by 2S albumin of plant proteins: a computational approach, Molecules. 27 (2022) 1685, https://doi.org/10.3390/molecules27051685.
[4] Agrawal, R.S., Nirmal, N.P., 2024. Technologies for extraction of bioactive compounds and its applications. pp. 1–20. https://doi.org/10.1007/978-1-0716-3601-5_1.
[5] A. Ahmad, S.R.S. Abdullah, H.A. Hasan, A.R. Othman, N.I. Ismail, Plant-based versus metal-based coagulants in aquaculture wastewater treatment: effect of mass ratio and settling time, J. Water. Process. Eng. 43 (2021) 102269, https://doi.org/10.1016/j.jwpe.2021.102269.
[6] A. Ahmad, S.R.S. Abdullah, H.A. Hasan, A.R. Othman, S.B. Kurniawan, Aquaculture wastewater treatment using plant-based coagulants: evaluating removal efficiency through the coagulation-flocculation process, Results. Chem. 7 (2024) 101390, https://doi.org/10.1016/j.rechem.2024.101390.
[7] A. Ahmad, S.B. Kurniawan, S.R.S. Abdullah, A.R. Othman, H.A. Hasan, Exploring the extraction methods for plant-based coagulants and their future approaches, Sci. Total. Environ. 818 (2022), https://doi.org/10.1016/j.scitotenv.2021.151668.
[8] H.M. Ahmed, M.A. El-Khateeb, N.Y. Mohamed, N.A. Sobhy, M.E. Fawzy, Evaluation of different natural waste materials as bio-coagulants for domestic wastewater treatment, Desalin. Water Treat. 317 (2024) 100034, https://doi.org/10.1016/j.dwt.2024.100034.
[9] R.S. Al-Wasify, S.R. Hamed, S. Ragab, Assessing the potential of de-oiled peanut (Arachis hypogea) seeds for surface water treatment: a sustainable alternative to chemical coagulants, Egypt. J. Aquat. Res. 49 (2023) 297–302, https://doi.org/10.1016/j.ejar.2023.04.003.
[10] M.M. Alnawajha, S.R.S. Abdullah, H.A. Hasan, A.R. Othman, S.B. Kurniawan, Effectiveness of using water-extracted Leucaena leucocephala seeds as a coagulant for turbid water treatment: effects of dosage, pH, mixing speed, mixing time, and settling time, Biomass Convers. Biorefinery 14 (2024) 11203–11216, https://doi.org/10.1007/s13399-022-03233-2.
[11] A.H. Amran, N.S. Zaidi, A. Syafiuddin, L.Z. Zhan, M.B. Bahrodin, M.A. Mehmood, R. Boopathy, Potential of carica papaya seed-derived bio-coagulant to remove turbidity from polluted water assessed through experimental and modeling-based study, Appl. Sci. 11 (2021), https://doi.org/10.3390/app11125715.
[12] E. Aranda-García, G.M. Chávez-Camarillo, E. Cristiani-Urbina, Effect of ionic strength and coexisting ions on the biosorption of divalent nickel by the acorn shell of the oak quercus crassipes humb. & bonpl, Processes 8 (2020) 1–17, https://doi.org/10.3390/pr8101229.
[13] O. Baatache, K. Derbal, A. Benalia, A. Khalfaoui, R. Bouchareb, A. Panico, A. Pizzi, Use of Pine cone as bio-coagulant for heavy metal removal from industrial wastewater: use of Box–Behnken design, Ind. Crops. Prod. 210 (2024) 118185, https://doi.org/10.1016/j.indcrop.2024.118185.
[14] A. Benalia, O. Baatache, K. Derbal, A. Khalfaoui, Z. Amrouci, A. Pizzi, A. Panico, The use of central composite design (CCD) to optimize and model the coagulation-flocculation process using a natural coagulant: application in jar test and semi-industrial scale, J. Water. Process. Eng. 57 (2024) 104704, https://doi.org/10.1016/j.jwpe.2023.104704.

[15] A. Benalia, K. Derbal, Z. Amrouci, O. Baatache, A. Khalfaoui, A. Pizzi, Application of plant-based coagulants and their mechanisms in water treatment: a review, J. Renew. Mater. 12 (2024) 667–698, https://doi.org/10.32604/jrm.2024.048306.

[16] M. Besharati Fard, D. Hamidi, J. Alavi, R. Jamshidian, A. Pendashteh, S. A. Mirbagheri, Saline oily wastewater treatment using Lallemantia mucilage as a natural coagulant: kinetic study, process optimization, and modeling, Ind. Crops. Prod. 163 (2021) 113326, https://doi.org/10.1016/j.indcrop.2021.113326.

[17] A. Boakye, F. Attiogbe, I. Emahi, Crescentia cujete fruit shell as green and efficient coagulant for water purification, Clean. Water 1 (2024) 100009, https://doi.org/10.1016/j.clwat.2024.100009.

[18] W.L.M. Braga, J.A. Roberto, C. Vaz, G.R.L. Samanamud, C.C.A. Loures, A. B. França, R.C.Z. Lofrano, L.L.R. Naves, Henrique José, J.H. De Freitas Gomes, F. L. Naves, Extraction and optimization of tannin from the flower of Musa sp. applied to the treatment of iron ore dump, J. Environ. Chem. Eng. 6 (2018) 4310–4317, https://doi.org/10.1016/j.jece.2018.05.058.

[19] M.A. Budihardjo, B.S. Ramadan, S.A. Putri, I.F.S. Wahyuningrum, F. I. Muhammad, Towards sustainability in higher-education institutions: analysis of contributing factors and appropriate strategies, Sustain 13 (2021), https://doi.org/10.3390/su13126562.

[20] F.P. Camacho, V.S. Sousa, R. Bergamasco, M. Ribau Teixeira, The use of Moringa oleifera as a natural coagulant in surface water treatment, Chem. Eng. J. 313 (2017) 226–237, https://doi.org/10.1016/j.cej.2016.12.031.

[21] S.-C. Chua, F.-K. Chong, M.A. Malek, M.R. Ul Mustafa, N. Ismail, W. Sujarwo, J.-W. Lim, Y.-C. Ho, Optimized use of ferric chloride and sesbania seed gum (SSG) as sustainable coagulant aid for turbidity reduction in drinking water treatment, Sustainability. 12 (2020) 2273, https://doi.org/10.3390/su12062273.

[22] S. Cojbasic, M. Turk Sekulic, S. Pap, M.A. Taggart, J. Prodanovic, Nature-based solutions for wastewater treatment: biodegradable freeze-dried powdered bio-flocculant, J. Water. Process. Eng. 65 (2024) 105863, https://doi.org/10.1016/j.jwpe.2024.105863.

[23] M.T. Dao, D.T. Vo, T.N. Tran, L.T.T.T. Hoang, V.C.N. Nguyen, Natural coagulants derived from Cassia fistula and tamarind seed for the removal of copper ions, Desalin. Water Treat. 289 (2023) 92–97, https://doi.org/10.5004/dwt.2023.22346.

[24] A. Daverey, N. Tiwari, K. Dutta, Utilization of extracts of Musa paradisica (banana) peels and Dolichos lablab (Indian bean) seeds as low-cost natural coagulants for turbidity removal from water, Environ. Sci. Pollut. Res. 26 (2019) 34177–34183, https://doi.org/10.1007/s11356-018-3850-9.

[25] M. DePaolis, S. De Respino, L. Samineni, S. Brighton, M. Kumar, Cottonseed extract as a coagulant for water treatment, Environ. Sci. Adv. 2 (2023) 227–234, https://doi.org/10.1039/D2VA00205A.

[26] S. Dey, G. Taraka Naga Veerendra, S.S. Anjaneya Babu Padavala, A.V. Phani Manoj, Evaluate the use of flower waste biosorbents for treatment of contaminated water, Water-Energy Nexus 6 (2023) 187–230, https://doi.org/10.1016/j.wen.2023.11.001.

[27] M. Dharsana, A.J. Prakash, Nano-banana peel bio-coagulant in applications for the treatment of turbid and river water, Desalin. Water Treat. 294 (2023) 100–110, https://doi.org/10.5004/dwt.2023.29491.

[28] E.O. dos Santos, C.C. Costa, P.L.S. Gonzáles, P.P. Ribas, C.E. Batista, Agroindustrial waste of guarana as potential coagulant agent for wastewater treatment, J. Water. Process. Eng. 67 (2024) 106165, https://doi.org/10.1016/j.jwpe.2024.106165.

[29] A.A.T. Dunoyer, R.E.G. Cuello, F.C. Castillo, Use of natural mucilage extracted from the Stenocereus griseus (Cardón Guajiro) plant as a coagulant in the treatment of domestic wastewater. Ambient. E Agua - an Interdiscip, J. Appl. Sci. 16 (2021) 1, https://doi.org/10.4136/ambi-agua.2705.

[30] J. El Gaayda, Y. Rachid, F.E. Titchou, I. Barra, A. Hsini, P.-S. Yap, W.-D. Oh, C. Swanson, M. Hamdani, R.A. Akbour, Optimizing removal of chromium (VI) ions from water by coagulation process using central composite design: effectiveness of grape seed as a green coagulant, Sep. Purif. Technol. 307 (2023) 122805, https://doi.org/10.1016/j.seppur.2022.122805.

[31] Y. Endale, Z.A. Samuel, S. Kebede, A.B. Bayu, Blended natural and synthetic coagulants for the COD and BOD removal from surface water; optimization by response surface methodology: the case of Gibe river, Heliyon. 10 (2024) e37961, https://doi.org/10.1016/j.heliyon.2024.e37961.

[32] M.B. Fard, D. Hamidi, K. Yetilmezsoy, J. Alavi, F. Hosseinpour, Utilization of Alyssum mucilage as a natural coagulant in oily-saline wastewater treatment, J. Water. Process. Eng. 40 (2021) 101763, https://doi.org/10.1016/j.jwpe.2020.101763.

[33] C. Feng, T. Lotti, R. Canziani, Y. Lin, C. Tagliabue, F. Malpei, Extracellular biopolymers recovered as raw biomaterials from waste granular sludge and potential applications: a critical review, Sci. Total. Environ. 753 (2021) 142051, https://doi.org/10.1016/j.scitotenv.2020.142051.

[34] Z. Fida, M.A. Tanoli, Q. Mahmood, M.S. Alamgir, D. Sajjad, Evaluation of plant-based natural extracts as coagulants for surface water treatment, Environ. Eng. Geosci. 30 (2024) 77–90, https://doi.org/10.21663/EEG-D-22-00051.

[35] M. Getahun, P. Asaithambi, A. Befekadu, E. Alemayehu, Chemical oxygen demand removal from wet coffee processing wastewater using indigenous natural coagulants: optimization through response surface methodology, Desalin. Water Treat. 317 (2024) 100217, https://doi.org/10.1016/j.dwt.2024.100217.

[36] M. Getahun, A. Befekadu, E. Alemayehu, Coagulation process for the removal of color and turbidity from wet coffee processing industry wastewater using bio-coagulant: optimization through central composite design, Heliyon. 10 (2024) e27584, https://doi.org/10.1016/j.heliyon.2024.e27584.

[37] C. Ghosh, M. Saha, A. Chakraborty, P. Ghosh, S. Chatterjee, Moringa oleifera: an edible medicinal plant, Int. J. Herb. Med. 11 (2023) 159–164, https://doi.org/10.22271/flora.2023.v11.i5b.902.

[38] L. Gopalakrishnan, K. Doriya, D.S. Kumar, Moringa oleifera: a review on nutritive importance and its medicinal application, Food Sci. Hum. Wellness 5 (2016) 49–56, https://doi.org/10.1016/j.fshw.2016.04.001.

[39] K. Grenda, J. Arnold, J.A.F. Gamelas, M.G. Rasteiro, Up-scaling of tannin-based coagulants for wastewater treatment: performance in a water treatment plant, Environ. Sci. Pollut. Res. 27 (2020) 1202–1213, https://doi.org/10.1007/s11356-018-2570-5.

[40] S.H. Guzmán-Maldonado, M.J. López-Manzano, T.J. Madera-Santana, C. A. Núñez-Colín, C.P. Grijalva-Verdugo, A.G. Villa-Lerma, J.R. Rodríguez-Núñez, Nutritional characterization of Moringa oleifera leaves, seeds, husks and flowers from two regions of Mexico, Agron. Colomb. 38 (2020) 287–297, https://doi.org/10.15446/agron.colomb.v38n2.82644.

[41] A. Hadadi, A. Imessaoudene, J.-C. Bollinger, A. Bouzaza, A. Amrane, H. Tahraoui, L. Mouni, Aleppo pine seeds (Pinus halepensis Mill.) as a promising novel green coagulant for the removal of Congo red dye: optimization via machine learning algorithm, J. Environ. Manage 331 (2023) 117286, https://doi.org/10.1016/j.jenvman.2023.117286.

[42] O. José de Oliveira, F. Francisco da Silva, F. Juliani, L. César Ferreira Motta Barbosa, T. Vieira Nunhes, Bibliometric method for mapping the State-of-the-art and identifying research gaps and trends in literature: an essential instrument to support the development of scientific projects, Sci. Recent Adv. (2019), https://doi.org/10.5772/intechopen.85856.

[43] H.M. Kalibbala, P.W. Olupot, O.M. Ambani, Synthesis and efficacy of cactus-banana peels composite as a natural coagulant for water treatment, Results. Eng. 17 (2023) 100945, https://doi.org/10.1016/j.rineng.2023.100945.

[44] S.U. Karaağaç, M.S.S. Abujazar, M. Kopan, S.S. Abu Amr, M.Y.D. Alazaiza, The potential use of olive seeds powder as plant-based natural coagulant for sustainable treatment of industrial wastewater, Desalin. Water Treat. 277 (2022) 169–176, https://doi.org/10.5004/dwt.2022.29036.

[45] D. Kenea, T. Denekew, R. Bulti, B. Olani, D. Temesgen, D. Sefiw, D. Beyene, M. Ebba, W. Mekonin, Investigation on surface water treatment using blended moringa oleifera seed and aloe vera plants as natural coagulants, South African J. Chem. Eng. 45 (2023) 294–304, https://doi.org/10.1016/j.sajce.2023.06.005.

[46] A. Khalid Salem, A. Fadhile Almansoory, I.A. Al-Baldawi, Potential plant leaves as sustainable green coagulant for turbidity removal, Heliyon. 9 (2023) e16278, https://doi.org/10.1016/j.heliyon.2023.e16278.

[47] B. Koul, N. Bhat, M. Abubakar, M. Mishra, A.P. Arukha, D. Yadav, Application of natural coagulants in water treatment: a sustainable alternative to chemicals, Water. (Basel) 14 (2022) 3751, https://doi.org/10.3390/w14223751.

[48] V. Kumar, A. Al-Gheethi, S.M. Asharuddin, N. Othman, Potential of cassava peels as a sustainable coagulant aid for institutional wastewater treatment: characterisation, optimisation and techno-economic analysis, Chem. Eng. J. 420 (2021) 127642, https://doi.org/10.1016/j.cej.2020.127642.

[49] S.B. Kurniawan, S.R.S. Abdullah, M.F. Imron, N.S.M. Said, N. Ismail, 'Izzati, H. A. Hasan, A.R. Othman, I.F. Purwanti, Challenges and opportunities of biocoagulant/bioflocculant application for drinking water and wastewater treatment and its potential for sludge recovery, Int. J. Environ. Res. Public Health 17 (2020) 1–33, https://doi.org/10.3390/ijerph17249312.

[50] S.B. Kurniawan, A. Ahmad, M.F. Imron, S.R.S. Abdullah, H.A. Hasan, A. R. Othman, E.P. Kuncoro, Performance of chemical-based vs Bio-based coagulants in treating aquaculture wastewater and cost-benefit analysis, Polish J. Environ. Stud. 32 (2023) 1177–1187, https://doi.org/10.15244/pjoes/156419.

[51] S.B. Kurniawan, A. Ahmad, N.S.M. Said, K. Gustinasari, S.R.S. Abdullah, M. F. Imron, The influence of preparation and pretreatment on the physicochemical properties and performance of plant-based biocoagulants in treating wastewater, Environ. Adv. 14 (2023), https://doi.org/10.1016/j.envadv.2023.100441.

[52] S.B. Kurniawan, A. Ahmad, N.S.M. Said, M.F. Imron, S.R.S. Abdullah, A. R. Othman, I.F. Purwanti, H.A. Hasan, Macrophytes as wastewater treatment agents: nutrient uptake and potential of produced biomass utilization toward circular economy initiatives, Sci. Total. Environ. 790 (2021) 148219, https://doi.org/10.1016/j.scitotenv.2021.148219.

[53] S.B. Kurniawan, M.F. Imron, C.E.N.C.E. Chik, A.A. Owodunni, A. Ahmad, M. M. Alnawajha, N.F.M. Rahim, N.S.M. Said, S.R.S. Abdullah, N.A. Kasan, S. Ismail, A.R. Othman, H.A. Hasan, What compound inside biocoagulants/bioflocculants is contributing the most to the coagulation and flocculation processes? Sci. Total. Environ. 806 (2022) 150902 https://doi.org/10.1016/j.scitotenv.2021.150902.

[54] F.A.B.M. Lanan, A. Selvarajoo, V. Sethu, S.K. Arumugasamy, Utilisation of natural plant-based fenugreek (Trigonella foenum-graecum) coagulant and okra (Abelmoschus escluentus) flocculant for palm oil mill effluent (POME) treatment, J. Environ. Chem. Eng. 9 (2021) 104667, https://doi.org/10.1016/j.jece.2020.104667.

[55] O.T.H. Le, L.N. Tran, V.T. Doan, Q.Van Pham, A.Van Ngo, H.H. Nguyen, Mucilage extracted from dragon fruit peel (Hylocereus undatus) as flocculant for treatment of dye wastewater by coagulation and flocculation process, Int. J. Polym. Sci. 2020 (2020) 1–9, https://doi.org/10.1155/2020/7468343.

[56] C.S. Lee, M.F. Chong, E. Binner, R. Gomes, J. Robinson, Techno-economic assessment of scale-up of bio-flocculant extraction and production by using okra as biomass feedstock, Chem. Eng. Res. Des. 132 (2018) 358–369, https://doi.org/10.1016/j.cherd.2018.01.050.

[57] E. Lester-Card, G. Smith, G. Lloyd, C. Tizaoui, A green approach for the treatment of oily steelworks wastewater using natural coagulant of Moringa oleifera seed, Bioresour. Technol. Reports 22 (2023) 101393, https://doi.org/10.1016/j.biteb.2023.101393.

[58] H. Liao, M. Tang, L. Luo, C. Li, F. Chiclana, X.J. Zeng, A bibliometric analysis and visualization of medical big data research, Sustain 10 (2018), https://doi.org/10.3390/su10010166.
[59] K.S. Lim, V. Sethu, A. Selvarajoo, Natural plant materials as coagulant and flocculants for the treatment of palm oil mill effluent. Mater, Today Proc 48 (2021) 871–887, https://doi.org/10.1016/j.matpr.2021.02.483.
[60] C. Liu, B. Gao, S. Wang, K. Guo, X. Shen, Q. Yue, X. Xu, Synthesis, characterization and flocculation performance of a novel sodium alginate-based flocculant, Carbohydr. Polym. 248 (2020) 116790, https://doi.org/10.1016/j.carbpol.2020.116790.
[61] P. Loganathan, J. Kandasamy, H. Ratnaweera, S. Vigneswaran, Use of wastewater alum-coagulation sludge as a phosphorus fertiliser – a mini review, Environ. Sci. Pollut. Res. 31 (2024) 18412–18421, https://doi.org/10.1007/s11356-024-32497-6.
[62] E.R.B. Magalhães, N.N. Fonseca de Menezes, F.L. Silva, J.W. Alves Garrido, M. Angélica dos Santos Bezerra Sousa, E.S.dos Santos, Effect of oil extraction on the composition, structure, and coagulant effect of Moringa oleifera seeds, J. Clean. Prod. 279 (2021) 123902, https://doi.org/10.1016/j.jclepro.2020.123902.
[63] S. Mathupreetha, W.M.A.P. Wijekoon, W.K.C.N. Dayanthi, L.F.U. Nusrath, Laboratory and pilot scale experiments with seeds extracts of yard long beans (Vigna unguiculata subsp. sesquipedalis) and snake gourd (trichosanthes cucumerina) as efficient coagulants for water treatment, Total Environ. Eng. 2 (2025) 100009, https://doi.org/10.1016/j.teengi.2025.100009.
[64] K. Meftah, S. Meftah, H. Lamkhanter, T. Bouzid, Y. Rezzak, S. Touil, A. Abid, Extraction and optimization of austrocylindropuntia subulata powder as a novel green coagulant, Desalin. Water Treat. 318 (2024) 100339, https://doi.org/10.1016/j.dwt.2024.100339.
[65] A.Y.A. Mohamed, P. Tuohy, M.G. Healy, D. Ó hUallacháin, O. Fenton, A. Siggins, Effects of coagulation pre-treatment on chemical and microbial properties of water-soil-plant systems of constructed wetlands, Chemosphere 362 (2024) 142745, https://doi.org/10.1016/j.chemosphere.2024.142745.
[66] M. Nasser, M.B. Abd El-latif, A. Mahmoud, D. Diaa, G. Kamal, H. Mahmoud, M. Emad, M. Hany, R. Hany, S. Mohamed, A. Farid, Utilization of Ziziphus spina-christi leaf extract-loaded chitosan nanoparticles in wastewater treatment and their impact on animal health, Int. J. Biol. Macromol. 282 (2024) 137441, https://doi.org/10.1016/j.ijbiomac.2024.137441.
[67] H.H. Nguyen, L.N. Tran, V.T. Doan, L.M. Luu, Q.T. Nguyen, Q. Van Pham, A. Van Ngo, O.T.H. Le, Coagulation and flocculation of dye wastewater by FeCl3 and mucilage extracted from dragon fruit peel (Hylocereus undatus) in regard of side effects caused by the use of PACl and PAM, Desalin. Water Treat. 250 (2022) 181–188, https://doi.org/10.5004/dwt.2022.28152.
[68] T.-T.-T. Nguyen, D.-T. Vo, T.-N. Tran, M.-T. Dao, Magnetic coagulant derived from Cassia fistula seed for real textile wastewater treatment: a pilot-scale study, Desalin. Water Treat. 319 (2024) 100426, https://doi.org/10.1016/j.dwt.2024.100426.
[69] T.A. Nguyen, H.D. Nguyen, B. Schmalz, L.L. Tran, Coagulation/floculation as a key unit in the decentralized surface water treatment systems in upland rural areas of Vietnam: results from a lab scale to a pilot scale system, Process. Saf. Environ. Prot. 194 (2025) 1194–1205, https://doi.org/10.1016/j.psep.2024.12.058.
[70] O.M. Nonfodji, J.K. Fatombi, T.A. Ahoyo, S.A. Osseni, T. Aminou, Performance of Moringa oleifera seeds protein and Moringa oleifera seeds protein-polyaluminum chloride composite coagulant in removing organic matter and antibiotic resistant bacteria from hospital wastewater, J. Water. Process. Eng. 33 (2020), https://doi.org/10.1016/j.jwpe.2019.101103.
[71] C. Onyutha, N. Auma, Turbidity reduction efficacies of seed kernels of Mango (Mangifera indica) genotypes in Uganda, Heliyon. 9 (2023) e21415, https://doi.org/10.1016/j.heliyon.2023.e21415.
[72] I. Pacheco, S. da, A.G.T. Alves, L.C. Santana, E.A.M. Ribeiro, S.C. Canobre, F. A. Amaral, Performance of cationic hemicelluloses arising from peanut shell residue from agroindustry in application as primary coagulant in physical-chemical treatment of dairy wastewater, J. Water. Process. Eng. 47 (2022) 102661, https://doi.org/10.1016/j.jwpe.2022.102661.
[73] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ 372 (2021), https://doi.org/10.1136/bmj.n71.
[74] D. Pal, Plant based biocoagulants from Cucurbita pepo and Cicer arietinum for improving water quality, Int. J. Agric. Environ. Biotechnol. 17 (2024), https://doi.org/10.30954/0974-1712.01.2024.5.
[75] N. Pandey, R. Gusain, S. Suthar, Exploring the efficacy of powered guar gum (Cyamopsis tetragonoloba) seeds, duckweed (Spirodela polyrhiza), and Indian plum (Ziziphus mauritiana) leaves in urban wastewater treatment, J. Clean. Prod. 264 (2020) 121680, https://doi.org/10.1016/j.jclepro.2020.121680.
[76] M.C. Posada-Velez, P. Pineda-Gomez, H.D. Martinez-Hernandez, Acetylated corn and potato starches as an alternative to the toxic inorganic coagulants/flocculants for wastewater treatment, Environ. Nanotechnology, Monit. Manag. 20 (2023) 100786, https://doi.org/10.1016/j.enmm.2023.100786.
[77] R. Premkumar, S. Rajesh, M. Prasanna venkadesh, Feasibility study on application of natural coagulants, J. Phys. Conf. Ser. 2070 (2021) 012186, https://doi.org/10.1088/1742-6596/2070/1/012186.
[78] M. Priyatharishini, N.M.M. Mokhtar, Performance of jackfruit (Artocarpus heterophyllus) peel coagulant in turbidity reduction under different pH of wastewater. Mater, Today Proc 46 (2021) 1818–1823, https://doi.org/10.1016/j.matpr.2020.10.248.
[79] J.D. Quintero A, M.-Á. Gómez-García, I. Dobrosz-Gómez, The scope of alum coagulation-flocculation assisted by slaked lime for the treatment of industrial wastewater containing highly concentrated Acid Black 194 dye. Optimization, molecular weight distribution and toxicity analysis, Results. Eng. 23 (2024) 102676, https://doi.org/10.1016/j.rineng.2024.102676.
[80] B.S. Ramadan, I. Rachman, N. Ikhlas, S.B. Kurniawan, M.F. Miftahadi, T. Matsumoto, A comprehensive review of domestic-open waste burning: recent trends, methodology comparison, and factors assessment, J. Mater. Cycles. Waste Manage 24 (2022) 1633–1647, https://doi.org/10.1007/s10163-022-01430-9.
[81] A. Rawson, Utilization and characterization of Moringa waste (Drumstick Peel) and evaluation of its functional properties, Int. J. Pure Appl. Biosci. 7 (2019) 611–617, https://doi.org/10.18782/2320-7051.7522.
[82] S. Rossi, S. Visigalli, F. Castillo Cascino, M. Mantovani, V. Mezzanotte, K. Parati, R. Canziani, A. Turolla, E. Ficara, Metal-based flocculation to harvest microalgae: a look beyond separation efficiency, Sci. Total. Environ. 799 (2021), https://doi.org/10.1016/j.scitotenv.2021.149395.
[83] R.A.R. Shah, S.R.S. Abdullah, H.A. Hasan, A.R. Othman, N. Ismail, ‘Izzati, Prospective plants as biocoagulant-flocculants for removal of total suspended solids in coffee effluent treatment, Chem. Eng. Res. Des. 198 (2023) 282–295, https://doi.org/10.1016/j.cherd.2023.09.002.
[84] K.P.Y. Shak, T.Y. Wu, Synthesis and characterization of a plant-based seed gum via etherification for effective treatment of high-strength agro-industrial wastewater, Chem. Eng. J. 307 (2017) 928–938, https://doi.org/10.1016/j.cej.2016.08.045.
[85] K.P.Y. Shak, T.Y. Wu, Optimized use of alum together with unmodified Cassia obtusifolia seed gum as a coagulant aid in treatment of palm oil mill effluent under natural pH of wastewater, Ind. Crops. Prod. 76 (2015) 1169–1178, https://doi.org/10.1016/j.indcrop.2015.07.072.
[86] D.W. Skaf, V.L. Punzi, J.T. Rolle, E. Cullen, Impact of Moringa Oleifera extraction conditions on zeta potential and coagulation effectiveness, J. Environ. Chem. Eng. 9 (2021), https://doi.org/10.1016/j.jece.2020.104687.
[87] H.N. Su, P.C. Lee, Mapping knowledge structure by keyword co-occurrence: a first look at journal papers in Technology Foresight, Scientometrics. 85 (2010) 65–79, https://doi.org/10.1007/s11192-010-0259-8.
[88] W. Subramonian, T.Y. Wu, S.-P. Chai, An application of response surface methodology for optimizing coagulation process of raw industrial effluent using Cassia obtusifolia seed gum together with alum, Ind. Crops. Prod. 70 (2015) 107–115, https://doi.org/10.1016/j.indcrop.2015.02.026.
[89] S. Sun, Z. Zhao, X. Cui, M. Huo, Z. Geng, The influence of residual coagulant Al on the biofilm EPS and membrane fouling potential in wastewater reclamation, Water (Switzerland) 12 (2020), https://doi.org/10.3390/W12041056.
[90] M. Suneetha, B.S. Sundar, K. Ravindhranath, Removal of fluoride from polluted waters using active carbon derived from barks of Vitex negundo plant, J. Anal. Sci. Technol. 6 (2015), https://doi.org/10.1186/s40543-014-0042-1.
[91] G.B. Suprayoga, M. Bakker, P. Witte, T. Spit, A systematic review of indicators to assess the sustainability of road infrastructure projects, Eur. Transp. Res. Rev. 12 (2020), https://doi.org/10.1186/s12544-020-0400-6.
[92] N. I. Syaichurrozi, L.N. Sari, A.P. Apriantika, Darsono Jayanudin, D. S. Khaerudini, Effect of coagulation-sedimentation pretreatment on methane production from Indonesian palm oil mill effluent and kinetics Bioresour. Technol. Reports 26 (2024) https://doi.org/10.1016/j.biteb.2024.101820.
[93] A.S. Taiwo, K. Adenike, O. Aderonke, Efficacy of a natural coagulant protein from Moringa oleifera (Lam) seeds in treatment of Opa reservoir water, Ile-Ife, Nigeria. Heliyon 6 (2020) e03335, https://doi.org/10.1016/j.heliyon.2020.e03335.
[94] T. Taşdemir, A. Taşdemir, Optimization of floc-flotation process in the removal of suspended particles from wastewater in a Jameson cell using central composite design, J. Water. Process. Eng. 52 (2023) 103552, https://doi.org/10.1016/j.jwpe.2023.103552.
[95] I.T. Tomasi, I. Santos, E. Gozubuyuk, O. Santos, R.A.R. Boaventura, C.M. S. Botelho, A sustainable solution for aquaculture wastewater treatment: evaluation of tannin-based and conventional coagulants, Chemosphere 377 (2025) 144320, https://doi.org/10.1016/j.chemosphere.2025.144320.
[96] A.G. Tomé, E.A.M. Ribeiro, M. Lima, R.F. Brocenschi, L.N.M. Ribeiro, e F. A. Amaral, Biorefinery of peanut shell agroindustrial lignocellulosic waste for synthesis of a natural coagulant applied in the treatment of dairy wastewater, J. Environ. Chem. Eng. 11 (2023) 111535, https://doi.org/10.1016/j.jece.2023.111535.
[97] C. Vaz, M. Almeida, P. Gonçalves, J. Roberto, A.B. França, R.C.Z. Lofrano, D. Fabiano, L.L.R. Naves, K. Milagres, F.L. Naves, Use of the extract of the flower of Musa sp., in the treatment from coagulation – Flocculation, of iron ore fines, J. Environ. Chem. Eng. 6 (2018) 1155–1160, https://doi.org/10.1016/j.jece.2018.01.047.
[98] P. Vega Andrade, C.F. Palanca, M.A.C. de Oliveira, C.Y.K. Ito, A.G. dos Reis, Use of Moringa oleifera seed as a natural coagulant in domestic wastewater tertiary treatment: physicochemical, cytotoxicity and bacterial load evaluation, J. Water. Process. Eng. 40 (2021) 101859, https://doi.org/10.1016/j.jwpe.2020.101859.
[99] D.J. Venegas-García, L.D. Wilson, Utilization of bioflocculants from flaxseed gum and fenugreek gum for the removal of arsenicals from water, Materials. (Basel) 15 (2022) 8691, https://doi.org/10.3390/ma15238691.
[100] G.D. Worku, S.N. Abate, Efficiency comparison of natural coagulants (Cactus pads and Moringa seeds) for treating textile wastewater (in the case of Kombolcha

textile industry), in: Heliyon., 11, 2025 e42379, https://doi.org/10.1016/j.heliyon.2025.e42379.

[101] A. Wyllie, T. Levett-Jones, M. DiGiacomo, P. Davidson, Exploring the experiences of early career academic nurses as they shape their career journey: a qualitative study, Nurse Educ. Today 76 (2019) 68–72, https://doi.org/10.1016/j.nedt.2019.01.021.

[102] C.-Y.Y. Yin, Emerging usage of plant-based coagulants for water and wastewater treatment, Process. Biochem. 45 (2010) 1437–1444, https://doi.org/10.1016/j.procbio.2010.05.030.

[103] J. Zhang, L. Song, L. Xu, Y. Fan, T. Wang, W. Tian, J. Ju, H. Xu, Knowledge domain and emerging trends in ferroptosis research: a bibliometric and Knowledge-map analysis, Front. Oncol. 11 (2021), https://doi.org/10.3389/fonc.2021.686726.

[104] Q. Zhang, F. Zhang, Y. Ni, S. Kokot, Effects of aluminum on amyloid-beta aggregation in the context of Alzheimer's disease, Arab. J. Chem. 12 (2019) 2897–2904, https://doi.org/10.1016/j.arabjc.2015.06.019.

[105] F. Zhao, F. Du, D. Shi, W. Zhou, Y. Jiang, L. Ma, Mapping research trends of retinal vein occlusion from 2009 to 2018: a bibliometric analysis, PeerJ. 2019 (2019) e7603, https://doi.org/10.7717/peerj.7603.

[106] A. Zourif, A. Benbiyi, S. Kouniba, M. El Guendouzi, Avocado seed as a natural coagulant for removing dyes and turbidity from wastewater: behnken Box design, sustainable reuse, and economic evaluation, Sustain. Chem. Pharm. 39 (2024) 101621, https://doi.org/10.1016/j.scp.2024.101621.

[107] A. Zourif, S. Kouniba, M. El Guendouzi, Valorization of palm petiole waste as natural biocoagulants: optimizing coagulation-flocculation for sustainable wastewater treatment and advancing circular economy in agriculture, Biocatal. Agric. Biotechnol. 63 (2025) 103473, https://doi.org/10.1016/j.bcab.2024.103473.