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Effectiveness of Natural Coagulants in Purification of Industrial Wastewater: A case of Cactus Pads and Watermelon Seeds

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ABSTRACT

This study assessed the potential of cactus pads and watermelon seeds as natural coagulants in industrial wastewater treatment. The global characterization of the two coagulants was done by using the Fourier Transform Infrared (FTIR) to determine the specific functional groups and by zeta potential measurements. A full factorial design was used to design the experiment and analyze the effect of three factors: coagulant dosage, settling time and particle size with three levels each and one replicate on the turbidity removal. ANOVA analyses were used to determine the significance of the factors. Results show that the amino and hydroxyl groups in cactus pads and watermelon seeds generate surface charges that enable interaction with charged particles and facilitate their destabilization, promoting coagulation. Negative zeta potential due to the ionization of the functional groups signified the potential of the cactus pads and watermelon seeds as natural coagulants. The highest removal efficiency achieved was 92% for both watermelon seeds and cactus pads, using a dose of 200 mg/L and 140 mg/L, respectively. The main effect and interaction plots for both coagulants reveal that an increase in both factors significantly impacted the removal efficiency. Results on particle size effects imply that larger particles have a greater tendency to settle and can be easily removed, resulting in the highest removal effectiveness. The combination of cactus pads and watermelon seeds was found to be significantly more effective in reducing turbidity in wastewater from industries, with a clearance rate of approximately 94%. More studies on the synergistic effect of combining the two coagulants are necessary. Utilizing cactus pads and watermelon seeds, for treating industrial wastewater can decrease reliance on and minimize the need for importing synthetic coagulants, which have negative environmental effects and pose significant health risks.

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INTRODUCTION

Depending on the industry and industrial activities, industrial wastewater varies greatly in flow and pollution strength. Industrial wastewater may contain suspended, colloidal and dissolved solids, toxic materials, pathogenic bacteria and heavy metals (Juma *et al.*, 2022; Sathya *et* *al.*, 2022). Textile industries use large volumes of water in every section to process various fabric types, especially during the sizing, de-sizing, scouring, bleaching, washing, dyeing, and printing processes (Owodunni and Ismail, 2021). These processes result in generating effluent high in color and turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and pH (Islam *et al.*, 2023; Kallawar and Bhanvase, 2024). Insufficient treatment and improper disposal of these effluents may harm the environment and human health. Environmental hazards may include eutrophication, groundwater pollution, and soil pollution, whereas health hazards may involve mutagenicity, carcinogenicity, endocrine disruption and neurotoxicity (Kishor *et al.*, 2021).

The presence of chemicals such as hydrosulfides and organically bound chlorine in the colorant used in textile industries may result in high turbid effluent that can drastically decrease oxygen concentration and block the passage of light through water bodies (Meghwal *et al.*, 2020; Khan and Malik, 2014). These chemicals can also cause allergic reactions and adverse effects on fetuses if they evaporate into the air we breathe or are absorbed through our skin (Iyiola *et al.*, 2024; Periyasamy, 2024; Kumar, 2022). To protect the environment and the public's health and ensure sustainable industrial operations, it is important to address issues related to managing industrial wastewater (Obaideen *et al.*, 2022). In developing countries, only 10% of the wastewater produced is treated, while the rest is discharged into the water bodies (Prabhakaran *et al.*, 2020). However, this small percentage is a result of the high importation cost of chemicals used for water treatment, which cannot be afforded by most developing countries (Kumar *et al.*, 2017).

Purification of industrial wastewater involves the removal of pollutants from wastewater and converting it into effluent that can be released into the water cycle. This effluent is supposed to have minimum environmental impacts so that it can be used in the industry and sometimes for domestic usage. Conventional treatment methods such as adsorption, coagulation, membrane separation, flotation, ozonation, ion exchange, evaporation and crystallization have been commonly employed for the treatment of wastewater from textile industries (Kumar and Saravanan, 2017). The coagulation process involves removing colloidal particles and organic wastes in wastewater by adding a coagulating agent. The agent destabilizes suspended particles in water by reacting with them to bring non-settling particles together into large, heavier masses of solids. The most useful coagulants have been synthetic ones like aluminum sulphate, ferric chloride and polyaluminium chloride (Ahmed *et al.*, 2016). Synthetic coagulants are usually expensive (Gandiwa *et al.*, 2020), toxic, associated with health issues, and thus non-sustainable (Koul *et al.*, 2022). Specific health risks caused by synthetic coagulants include neurological disorders such as Alzheimer’s disease, dementia, encephalopathy, and Hippocampal neuron staining (Koul *et al.*, 2022). Residues of metals from synthetic coagulants are said to remain in the water even after treatment and the sludge produced from the treatment has also been affirmed to be hazardous and non-biodegradable, causing harm to the environment (Owodunni and Ismail, 2021). Natural coagulants are a sustainable alternative to synthetic because they are readily available, economical, easy to use, biodegradable, non-toxic, eco-friendly, effective (Nimesha *et al.*, 2022), and generate lower sludge volumes (Alazaiza *et al.*, 2022; Koul *et al.*, 2022; Gautam and Saini, 2020). The transition from the use of chemical to natural coagulants is highly recommended due to their incomparable performance to that of the chemical coagulant (Bahrodin *et al.*, 2021; Koul *et* *al.*, 2022). Most natural coagulants have been employed in industrial wastewater treatment, such as moringa oleifera, nirmali seeds, tannin, watermelon rinds (Wang *et al.*, 2022; Aguilar-Rosero *et al.*, 2022); sesame seeds (Abood *et al.*, 2017); cassava, maize, chitosan, and cactus opuntia ficas indica (Onditi *et al.*, 2016; Prabhakaran *et al.*, 2020; Cañón *et al.*, 2021; Bouaouinea *et al.*, 2021); and broad beans (Misau and Yusuf, 2016; Muhammad *et al.*, 2015). However, little research has been conducted on textile industry wastewater and the usage of watermelon seeds and cactus pads (Karam *et al.*, 2021; Rebah and Siddeeg, 2017). Watermelon seeds exhibit adsorption characteristics, which aid in the solid-liquid separation of suspended particles in solution (Adeoye *et al.*, 2020; Ahmed *et al.*, 2021). Cactus pads offer similar qualities and are widely available in semi-arid locations and gardens (Karanja, 2017). Despite the significant potential of watermelon seeds and cactus pads, their use as natural coagulants is limited by scant information on their efficacy in the treatment of wastewater from textile industries. In order to reduce dependency on synthetic coagulants, which have detrimental effects on the environment and present serious health hazards, this study intends to examine the effects of natural coagulants (watermelon seeds and cactus pads) on turbidity removal in relation to dosage, contact time, and particle size.

MATERIAL AND METHODS

Materials collection and preparation

The materials used in this study were industrial wastewater from a textile industry, Cactus pads and watermelon seeds. Cactus pads were collected from an open space near Mbezi Louis, while watermelon seeds were obtained from a fruit store in Buguruni, all in Dar es Salaam. The wastewater samples from a textile industry were collected from a regulating pool capable of holding up to 550 m^3. The regulating pool contained blower pumps at the bottom for continuous aeration of wastewater from industrial processes before treatment. During the collection of wastewater samples, the sampling bottle was first washed by using dilute nitric acid and then rinsed with deionized water. The bottle was then rinsed with a specific sample of wastewater before sampling and thereafter carried to the Chemical and Process Engineering Laboratory at the University of Dar es Salaam (UDSM) for analysis. Preservation of the water samples was done by adding 2 drops of 70% concentrated nitric acid for every 1 litre of wastewater to make 2% concentration, and then stored at a temperature below 16°C in a refrigerator for 4 days before analysis.

Characterization of the industrial wastewater

The characteristics of industrial wastewater samples were determined by measuring physical and chemical parameters including turbidity, total suspended solids, total dissolved solids, electric conductivity, pH, colour, and organic content. The pH of the wastewater samples was determined according to APHA Standard Method 8156 by using a digital pH meter (Roslin, 2015). Turbidity determination was performed by using a turbidity meter as expressed in Nephelometric turbidity units (NTU) (Owodunni and Ismail, 2021). Calibration was done to the turbidity meter using standards of known turbidity. The cuvettes were rinsed with distilled water to ensure they were clean and free from contaminants. The sample was filtered through a filter paper (0.45 microns) to remove any large particles that could interfere with the measurement.

The electrical conductivity was measured according to APHA standard method 2510 B by using a conductometer (Eutech). Total dissolved solids (TDS) were measured by using a portable HACH sension 156 conductometer as described by Kihampa *et al.*, (2016). APHA Standard Method 5220 -

D was used to determine the chemical oxygen demand (COD) using a colorimeter. Samples of the wastewater were filtered to remove any suspended solids and diluted with distilled water to ensure that the COD falls within the range of the standard curve. A known volume of the diluted sample was pipetted into a digestion vial and a potassium dichromate solution and sulphuric acid solution was added. The vial in the COD digester was mixed well and heated for 2 hours. After digestion, the sample was cooled and a colorimetric reagent was added, consisting of a mixture of a solution of silver sulphate and mercuric sulphate. The mixture was allowed to stand for 10 minutes to allow any turbidity to settle, and then the absorbance of the supernatant was measured at 420 nm using a colorimeter. The COD of the sample was calculated using the standard curve, which relates the absorbance at 420 nm to the concentration of COD. Heavy metals were measured by using a Microwave plasma atomic emission spectrometry MP-AES (EPA3050B/200.7B).

Coagulants preparation

Figure 1 illustrates six samples of cactus pads and watermelon seeds used as coagulants.

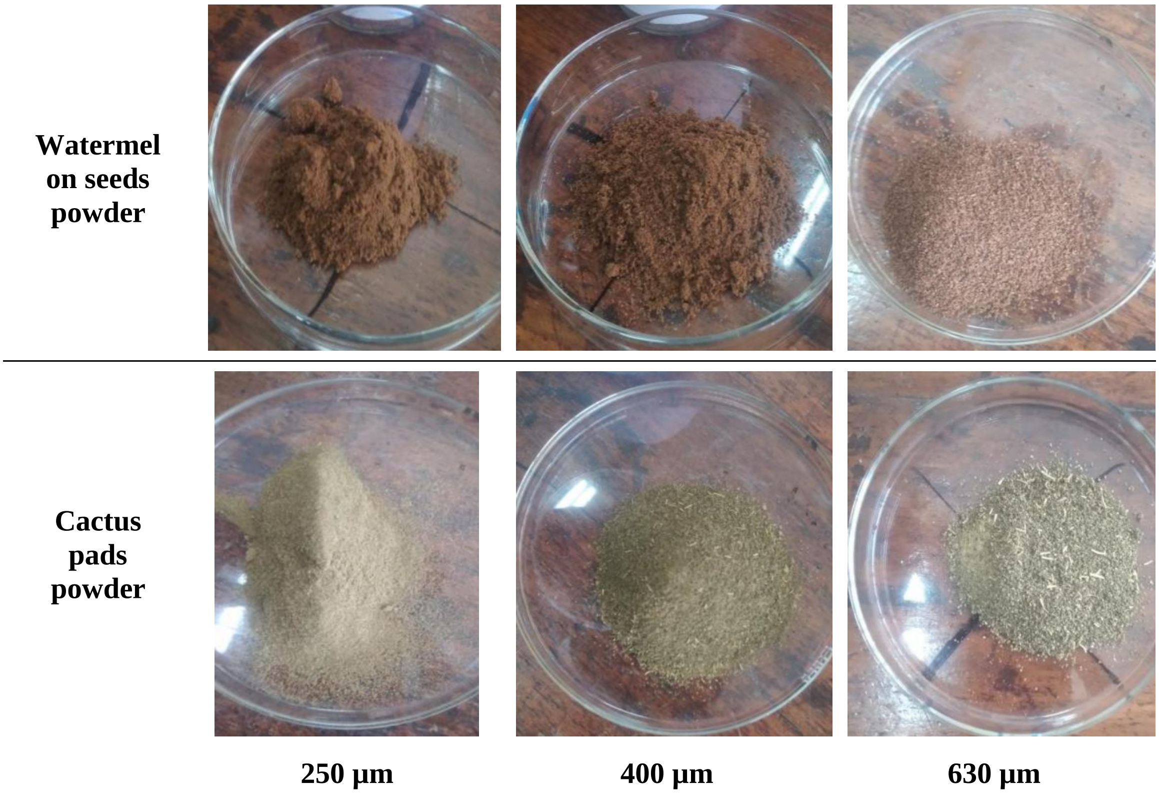

Figure 1: Prepared watermelon seeds and cactus pads powder with their sieve sizes.

Cactus pad coagulant preparation

Cactus pads to be used as coagulants were removed thorns by using a knife then washed with distilled water to remove dust and any water-soluble impurities. The pads were then reduced into small pieces of about 1 cm. The pieces were dried in an oven at about 80˚C for 48 hours until they became brittle to preserve coagulation properties and then milled using a milling machine. The milled sample was washed with 10 ml of hot distilled water of about 60˚C and precipitated with 15 ml of 50% concentration ethanol and dried in an oven at 80˚C until dried cake was obtained. The sample was then grinded by the milling machine and sieved through a mesh of size 250, 400, and 630 µm to obtain cactus powder mucilage that was used as a coagulant for treating wastewater. The powdered mucilage was placed in a plastic bag and then stored in a desiccator at room temperature with a relative humidity of 30% to ensure cactus pads remained viable as a coagulant until characterization.

Watermelon seeds coagulant preparation
The seeds were manually sorted to remove any damaged seeds then washed with distilled water. The seeds were then dried in an oven at 80˚C for 24 hours and crushed into tiny granules with a milling machine. The crushed watermelon seeds were washed with hot distilled water of about 80˚C to remove oil. The resulting cake was dried in an oven at 40˚C for one hour, grinded and then sieved with fine mesh sieve to obtain 250, 400 and 630 µm powder to be used as a coagulant. After preparation, 500 g of watermelon seeds produced 22.6 g for 630 µm, 19.8 g for 400 µm, and 21.4 g for 250 µm, with an optimal dosage of 200 mg/L for both coagulants as per the experimental design.

Coagulants Characterization

This was done to study the behaviors, including the chemical makeup of the cactus pads and watermelon seeds and the zeta potential of the coagulants.

Functional groups of cactus pads
The functional groups present in the sample such as carboxylic acid, alcohols, and amine groups of the coagulants were determined by using an Attenuated Total Reflectance - Fourier Transform Infrared spectroscopy (ATR-FTIR). The potassium bromide (KBr) cell was rinsed with ethanol, cleaned, and dried. For each analysis, 0.3 g of each of the prepared coagulants, either watermelon seeds or cactus pads, were mixed with 0.1 g of powdered potassium bromide. The mixed sample powder was evenly spread across the sample holder ready for analysis. The infrared spectrum of the sample was collected in the range of 4000 to 400 cm^{-1}, with a resolution of 4 cm^{-1} and a total of 32 scans.

Zeta potential
Difference in voltage between the diffuse layer surface and water is the zeta potential. The amount of the zeta potential indicates the quality of colloid particle repulsion and the distance needed to bring them together. Zeta potential analysis method by Schultz, (2016) was adopted and used. This was done by using the Conductometric titration method. The raw data collected included pH, conductivity of suspension and titre volume in which the titrant was sodium chloride of mass concentration 491 mg/L. As the titrant was added, the electrical conductivity of solution changed due to movement of charged particles and the change was measured using a conductometer. The endpoint of titration was determined when the concentrations of the titrant and particles became stoichiometrically equivalent, resulting in no further change in conductivity. At this point the net surface charge of the particles is zero and the zeta potential of the suspension was determined using equation 1.

$$\zeta = \left(\frac{2.303\,RT}{F}\right)\left(\frac{d(\log k)}{d(\log [c])}\right) \ldots\ldots\ldots (1)$$

Where **ζ** is zeta potential, R is the gas constant, T is the temperature, F is the Faraday constant, c is the titrant concentration and k is the conductivity of solution.

Treatment of the industrial wastewater

The coagulation method as described by Maurya and Daverey, (2018) was adopted with slight modification on the apparatus used. Laboratory Jar testing apparatus with a four-paddle rotor for 500 - 1000 mL beakers was used. The jar test is a common laboratory procedure used to determine the optimum operating conditions for water or wastewater treatment. This method allows adjustments in pH, variations in coagulant or polymer dose, alternating mixing speeds, or testing of different coagulant or polymer types, on a small scale in order to predict the functioning of a large-scale treatment operation (Pivokonský *et al.,* 2022; Govindaraj *et al.,* 2022). All experiments were performed using 500 mL of wastewater in beakers. Four beakers were prepared and filled with samples of the industrial wastewater followed by an addition of prepared coagulants. The centre of beakers was properly aligned with impeller shafts to enable proper mixing by stirring (Figure 2). The impeller speed was first set at 200 rpm for rapid mixing to evenly disperse the coagulant. After 3 minutes, the speed was decreased to 40 rpm for gradual mixing to maintain a consistent suspension of floc particles in the water within 30 minutes.

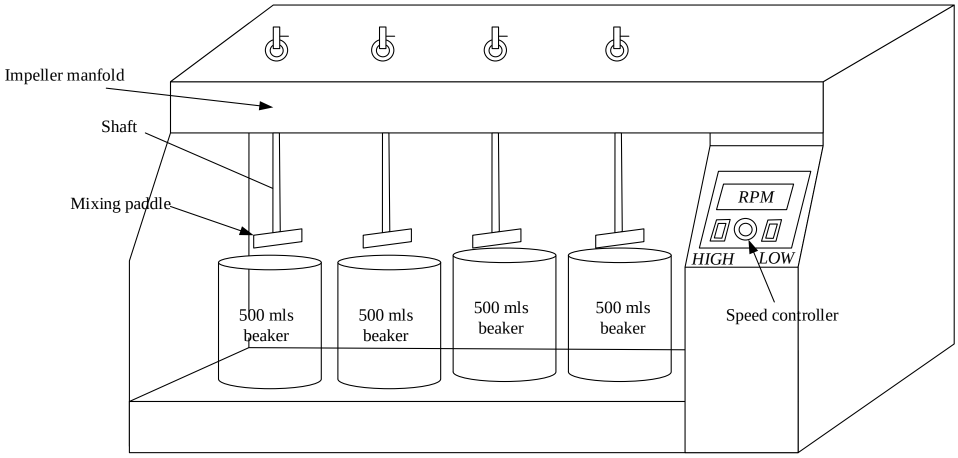

Figure 2: The jar test apparatus.

Design of Experiment for wastewater treatments

Minitab software Version 21 was used to design the experiment and analyse the results. A full factorial design (multilevel design) was used to design the experiment and analyse the effect of factors on the treatment of wastewater from a textile industry. Three factors: coagulant dosage, settling time and particle size with three levels each and one replicate was used. ANOVA analyses were used to determine the significance of the factors, and the main and interaction plots were used to analyse the effect of factors. Table 1 show the design summary, factor levels used for both cactus pads and watermelon seeds; when they were used separately as coagulants representing 100% and 0% ratios for each. The minimum (Level 1) and maximum (level 3) values were obtained from literatures (Precious Sibiya *et al.* 2021) with slight modification in the intermediate levels especially on particle sizes to meet the available mesh size.

Table 1: Design summary and coagulation factors and their levels

Design Summary

Factors:	3	Replicates:	1
Base runs:	27	Total runs:	27
Base blocks:	1	Total blocks:	1

Factors	**Level 1**	**Level 2**	**Level 3**
Coagulant dosage (mg/L)	80	140	200
Settling time (hours)	1	2	3
Particle size (µm)	250	400	630

The effect of combining the two coagulants in treatment of industrial wastewater was also analyzed. The Mixing ratio for coagulant dosage when combining cactus pads and watermelon seeds is given in Table 2.

Table 2: Number of runs, mixing ratio and coagulant dosage when combining the two coagulants

Run Order	**Mixing ratio (%)**		**Coagulant dosage (mg/L)**	
	Cactus pads	**Watermelon seeds**	**Cactus pads**	**Watermelon seeds**
1	80	20	160	40
2	60	40	120	80
3	40	60	80	120
4	20	80	40	160

Determination of the effectiveness of the coagulants

The efficacy of coagulants was assessed by determining their removal efficiencies using Equation 2. The effectiveness was determined by the characteristics of the industrial wastewater including turbidity, total dissolved solids and Chemical oxygen demand (COD) by comparing their concentration in the effluent before and after treatment.

$$Removal\ (\%) = \frac{Initial\ concentration - Final\ concentration}{Initial\ concentration} x\ 100..(2)$$

RESULTS AND DISCUSSION

Characterization of the industrial wastewater

Table 3 shows the results for properties of wastewater from a textile industry.

Table 3: Properties of untreated wastewater from a textile industry

Parameter	**Wastewater from textile industry**	**Required Range (TBS, 2019)**
pH	7.42	6.5 – 8.5
Turbidity [NTU]	72.9	< 30
E.C [µS/cm]	5740	1335
TDS [mg/L]	2640	<500
COD [mg/L]	490	<100
Copper [mg/L]	0.56	≤0.20
Iron [mg/L]	0.52	≤5.0

It was observed that TDS, turbidity and COD were above the recommended levels for wastewater. It is recommended that turbidity for treated industrial wastewater should be less than 30 NTU (TBS, 2019). High turbidity levels may be caused by the presence of high dissolved solids; dissolved organic, and the presence of algae and bacteria in the collected samples. The textile industry produces wastewater that is within the range of pH from 6 to 9 as recommended by TBS. However, the slightly higher pH values observed were due to use of bleaching agents in the industrial process, such as Sodium Hypochlorite. Higher electrical conductivity can be related to the presence of more dissolved solids in the water. This is due to the involvement of reactive dyes in salt based on dyeing processes, which significantly increase the conductivity. The presence of metals copper and iron observed was due to the contamination in equipment like tanks, pipes, valves and heat exchangers. The chemical oxygen demand appeared to have exceeded the recommended level, which could have been attributed to several industrial processes like bleaching, washing, and dyeing.

Coagulant characterization

Functional group analysis

The analysis enabled the presence of important functional groups from the cactus pads and watermelon seeds. The groups, including carboxyl, hydroxyl, amides, aromatic rings, and carbonyl groups, seemed to be found in the prepared samples of coagulants. These groups are better for coagulation as they interact with charged particles, destabilize them, and provide a bridge for the particles to adsorb upon (Otálora *et al.*, 2022).

Functional group analysis for Cactus pad coagulants

Figure 3 shows the FTIR spectrum of powdered mucilage Cactus pads showing the wavenumbers of the peaks corresponding to the functional groups. The FTIR spectrum of the powdered cactus pads has an absorption peak at 3930 cm^{-1}, showing the existence of hydroxyl (OH) bonds. The absorption at 3250 was assigned to the stretching vibration of primary amide $-NH_2$. The band observed at 1566 cm^{-1} indicates the presence of a carbonyl functional group present in the amide II region, showing the presence of a-helices structure of the protein or the deformation of the amide (N–H) stretch. The presence of the amino groups ($-NH_2$) in proteins interacts with charged particles and promotes coagulation. The hydroxyl groups (–OH) provide surface charges to the cactus pads for interacting with charged particles and destabilizing them. The carboxyl groups act as ligands forming complexes with metal ions in water and are responsible for promoting the coagulation process, providing a bridge for the particles to adsorb upon (Maurya and Daverey, 2018).

Table 4 shows the possible functional groups observed for powdered cactus pads with the corresponding wavenumbers.

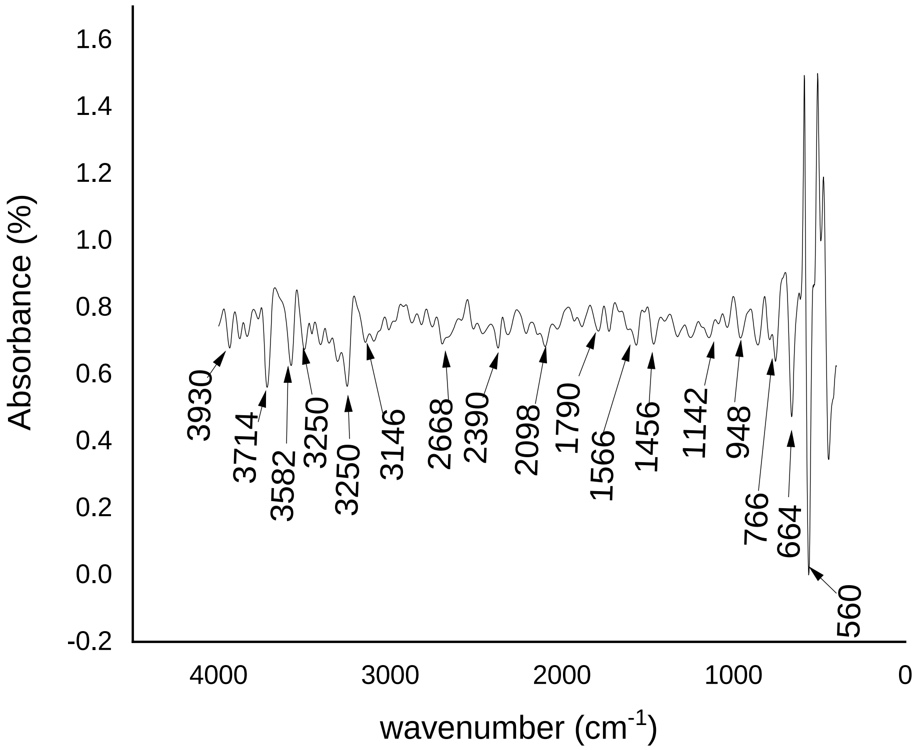

Figure 3: FTIR spectrum of the powdered Cactus pads.

Table 4: Wavenumber and Functional groups of Cactus pads

Wavenumber [cm^{-1}]	**Functional group (Vibration type)**
3930	Hydroxyl OH bonded
3250	Primary amide $-NH_2$ (stretching vibration)
1566	Primary amine N – H (bending vibration) also carbonyl functional group present in the amide II

Functional group analysis for Watermelon seeds coagulants

Figure 4 shows the FTIR spectrum of watermelon seeds indicating the peaks for possible functional groups with their corresponding wavenumbers.

The FTIR spectrum of the powdered watermelon seeds showed a band at 3508, indicating stretching vibration of primary amine N–H. The absorption observed at around 2884 cm^{-1} was assigned to the stretching asymmetric C-H vibrations. The absorption observed in 1684 was attributed to the vibration frequency of the Carbonyl (C=O) group of amides present in the protein portion. The existence of organic functional amide groups (– CONH) in the protein plays a role in the interaction with charged particles. The carboxylic groups facilitate the aggregation of particles, leading to the coagulation activity of seeds. This tendency has also been reported by Zainal *et al.,* (2021). These coagulant characteristics for both watermelon seeds and cactus pads are also reported by Said & Msuya, (2024). Table 5 shows the wavenumber of peaks and their possible functional groups found in powdered watermelon seeds

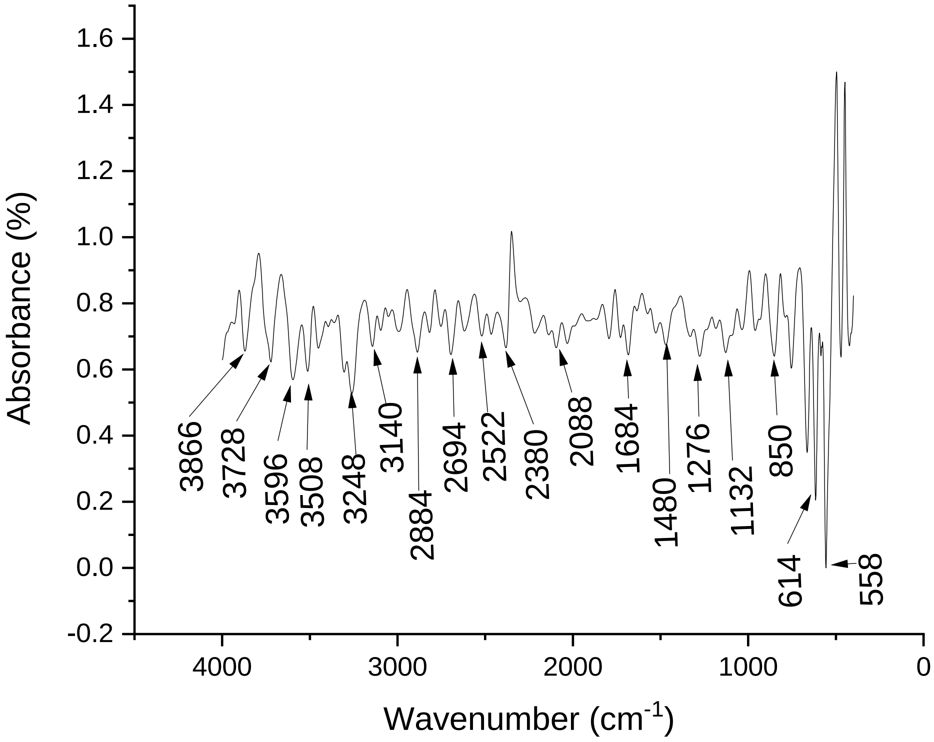

Figure 4: FTIR spectrum of Watermelon seeds.

Table 5: Wavenumber and Functional groups of Watermelon seeds

Wavenumber [cm^{-1}]	Functional group (Vibration type)
3508	Primary amine N – H (stretching vibration)
2884	$-CH_3$ Symmetric stretching vibration
1684	Carbonyl group (C = O) (stretching vibration)

As the titrant was added, the electrical conductivity of the solution changed due to the movement of charged particles for both cactus pads and watermelon seeds. The results indicated negative zeta potential values for both samples, suggesting the anionic character of the coagulants. This is mostly attributed to the functional groups' ionization, as Lek *et al.* (2018) explained. The negative zeta potential readings indicate the presence of a negative charge in the cactus pads and watermelon seeds, which act as an anionic polyelectrolyte biopolymer. The negative charge of the polysaccharide indicates its potential to coagulate through an adsorption bridge mechanism due to dipolar interaction with divalent cations. The negative charge may be attributed to the ionization of the functional groups. The decrease in zeta potential may be attributed to the effect of low pH as described by Kamble *et al.*, (2022). The results obtained were consistent with those reported by Otálora *et al.* (2022).

Effect of settling time and dosage of Cactus pads on turbidity removal

Figure 7 shows the effect of cactus pad dosage on turbidity removal while treating wastewater from the industry.

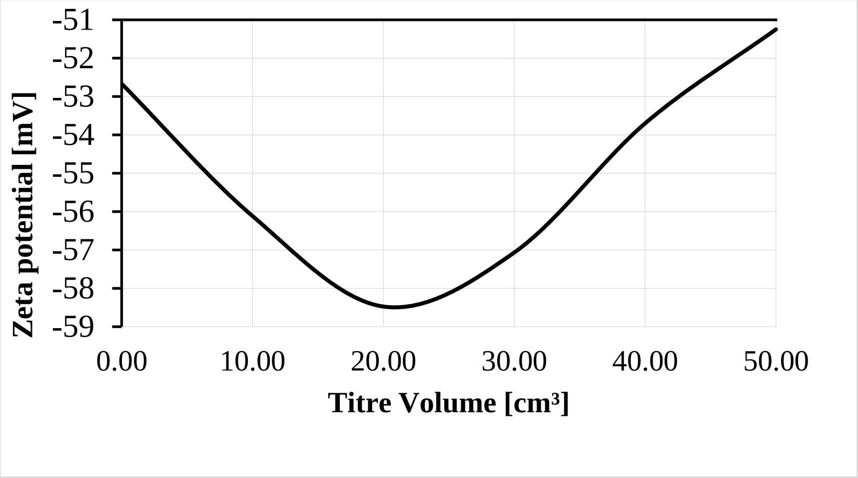

Figure 5: Zeta potential analysis for cactus pads.

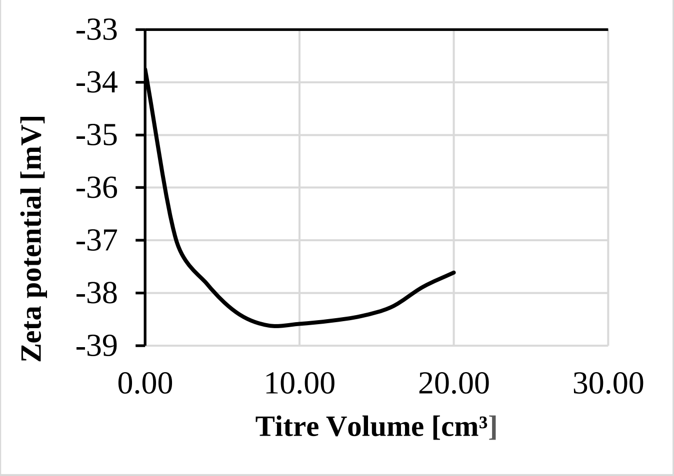

Figure 6: Zeta potential analysis for watermelon seeds

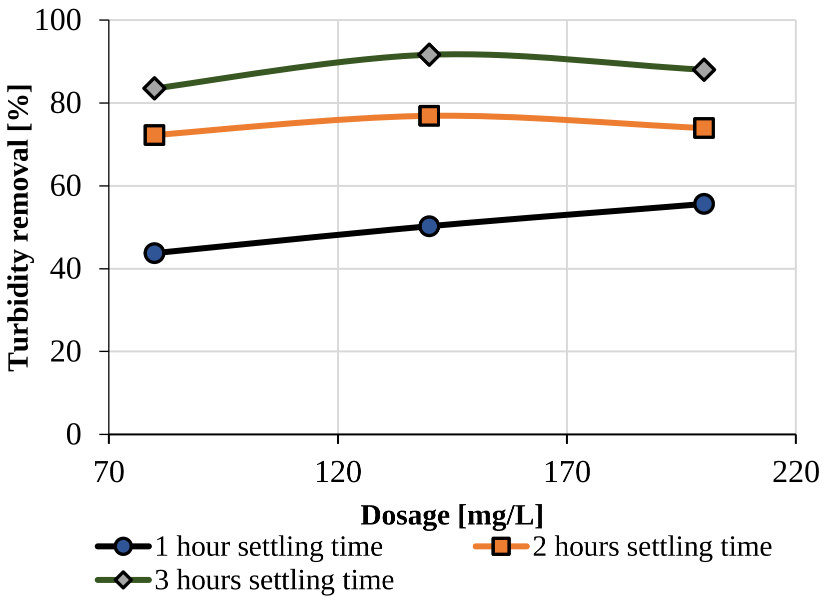

Figure 7: Dosage and settling time effect on turbidity removal using cactus pads coagulants.

Turbidity removal increased as the coagulant dosage increased for all the settling times. The highest performance in this study was 92% with a dose of 140 mg/L and a three-hour settling time was used. Turbidity was significantly reduced when the coagulant dosage exceeded 140 mg/L. This may be attributed to colloid neutralization and precipitation at the optimal dosage. As a result, when a high dosage is used, excess coagulants are released into the water without reacting with the oppositely charged colloidal particles, resulting in turbidity increasing. The observed trend of settling for one hour was found to be less efficient, with the optimum dose being 200 mg/L, resulting in a removal efficiency of 56%. However, a three-hour settling time appeared to be best for reducing turbidity since it provided enough time for a wide range of suspended materials to settle. This tendency was also observed by Said and Msuya, (2024) when treating pond water and Zainal *et al.*, (2021) when utilizing *jatropha curcas* to treat concentrated stabilized landfill leachate.

Effect of settling time and dosage of Watermelon seeds on turbidity removal

Figure 8 shows the effect of watermelon seeds dosage for removing turbidity while treating wastewater from the industry. The performance trend showed that increasing the dosage made watermelon seeds more effective at removing turbidity. However, the 80 mg/L dosage removed less turbidity in all three settling time scenarios. The best turbidity removal rate was 92% when 200 mg/L was applied for two and three-hour settling times. This differs from the trend observed in cactus pads, where efficiency was lower for 200 mg/L than for 140 mg/L. Khader *et al.* (2018) report a similar trend in turbidity removal using the majority of natural coagulants. The trend for one-hour and two-settling times was found to be less efficient. However, three hours of settling time proved to be the most effective for removing turbidity as it allowed a wide range of suspended materials to settle.

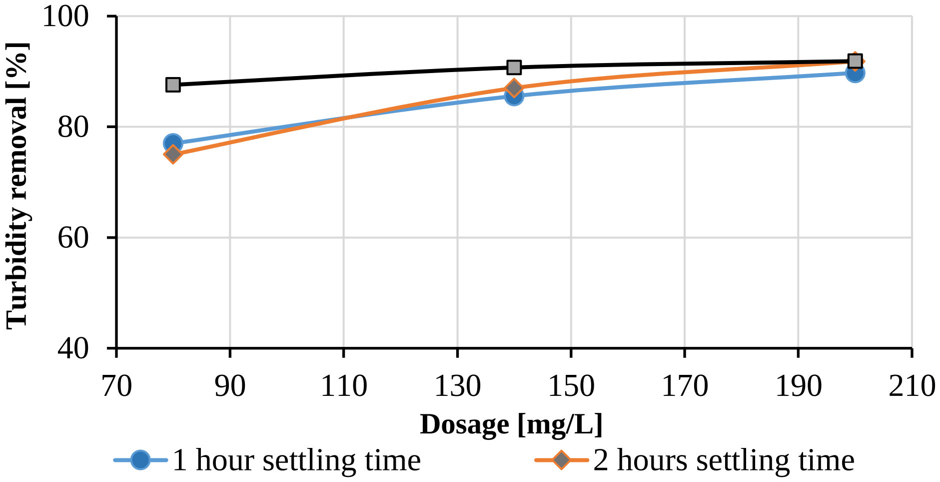

Figure 8: Dosage and settling time effect on turbidity removal using Watermelon seeds coagulants.

Effect of settling time and dosage of Cactus pads and watermelon seeds on pH

The effect of settling time and coagulant dosage on maintaining pH for both cactus pads and watermelon seeds is shown in Figure 9. The initial pH for the wastewater to be treated was 7.42 for all dosages. For both coagulants, there were slight increases in pH with an increase in coagulant dosage for all settling times. For cactus pads, the increase in pH was observed immediately after dosage for all dosage sizes followed by sharp increase in pH as the dosage was increased. This is attributed to the acidic nature of cactus pads as shown in the FTIR analysis. For watermelon seeds, the pH was almost the same as the initial pH at the lowest dosage. As the dosage was increased the pH also tends to slightly increase. For all coagulants, the increase in dosage increased the pH despite the difference in settling time. This trend can be related to reported limitations of many natural coagulants to affect the pH and on the dosage size (Bahrodin *et al.*, 2021). It is clear from the Figures that the treatability performance of cactus pads and watermelon seeds in the range of dosage selected in this study did not affect the pH since all the pH values were still within the recommended values.

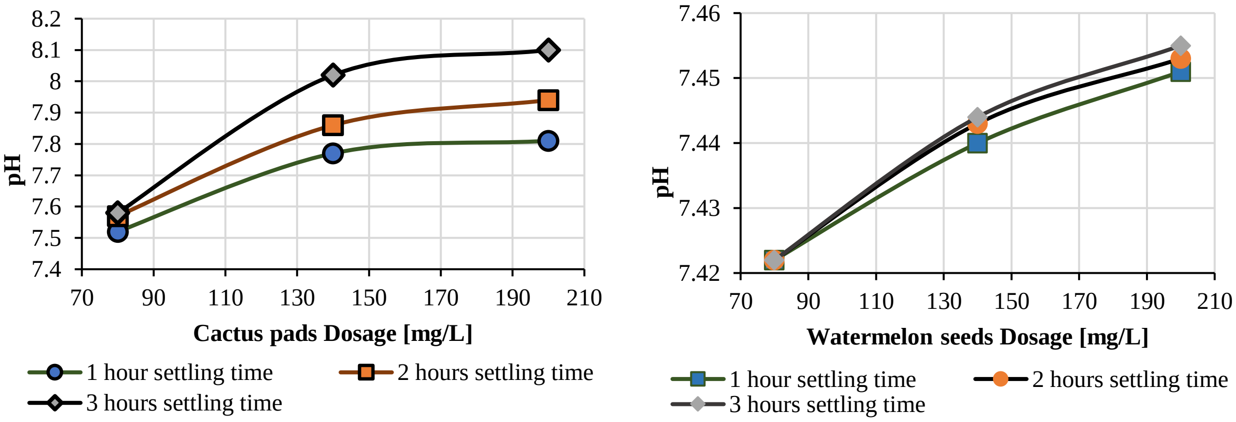

Figure 9: Effect of dosage and settling time effect on pH.

Effect of combining Cactus pads and watermelon seeds in turbidity removal

Figure 10 shows the effect of coagulant dosage and settling time on turbidity removal when cactus pads and watermelon seeds were combined in different ratios.

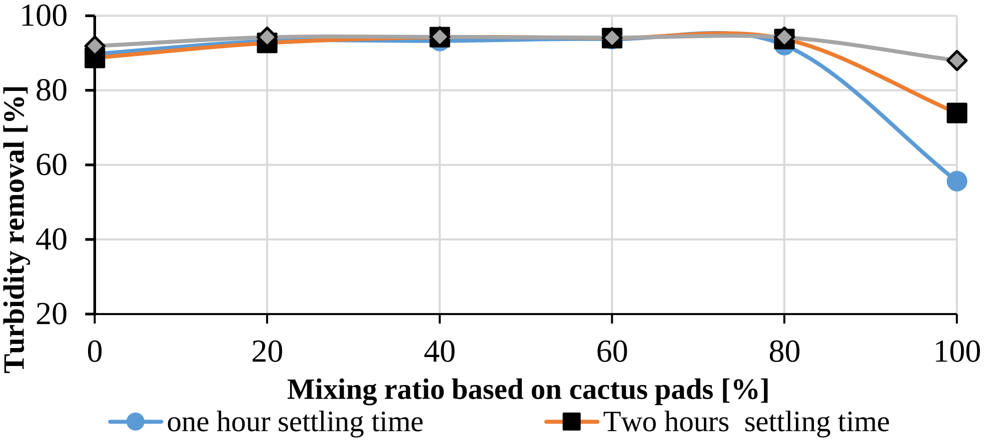

Figure 10: Effect of Dosage and settling time on turbidity removal when combining Cactus pads and Watermelon seeds coagulants.

Turbidity was effectively removed when the two coagulants were combined, owing to the combining effect of functional groups in the coagulation process. When the combination of two coagulants was used, the removal efficiency was high (more than 90%) for all settling times used and for all mixing ratios up to 80% cactus pads. Observed changes were when mixing ratios were above 80% cactus pads. The lowest removal efficiency was obtained with a dosage of 100% cactus pads (200 mg/L) and 0% watermelon seeds. This shows that watermelon seeds are more effective than cactus pads.

Statistical analysis of the cactus pads and watermelon seeds coagulants

Figure 11 and Figure 12 show the main effect and interaction plots of dosage, settling time, and particle size on turbidity removal when cactus pads were used as coagulants.

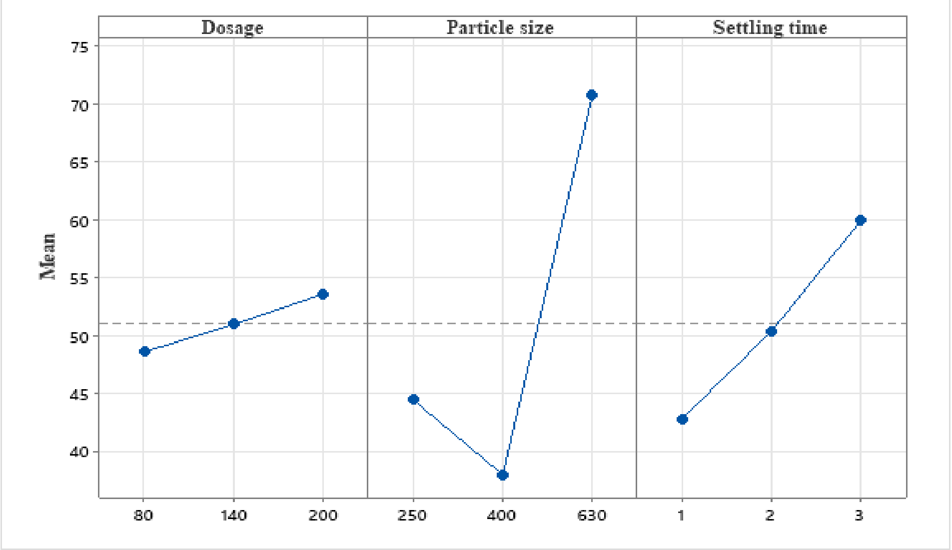

Figure 11: Main effect plot for turbidity retained while using cactus pads coagulants.

The main effect plot for cactus pads (Figure 11) clearly indicates that increasing the dose levels leads to a more effective removal of turbidity. This pattern shows that as the dosage increases, the turbidity removal increases. The settling time plot demonstrates a noticeable decrease, suggesting that the water became clearer as the duration of particle settling increased. The main effect plot for particle size demonstrates an increasing pattern with an increase in particle sizes. These findings indicate that the decrease in turbidity can be attributed to the presence of smaller particles, and the highest level of removal effectiveness was observed with the biggest particle size. This implies that larger particles have a greater tendency to settle and can be easily removed. To minimize the unexpected trend observed when the 400 µm particle size was utilized, it is recommended to optimize the distribution of particle sizes on removal efficiency. There is a significant interaction between dosage and settling time when higher dosages were used, as shown in Figure 12. When large particles are used during treatment the interaction between suspended particles and polygalactruronic acid is slow resulting in poor chemisorption (Said and Msuya, 2024).

Figures 13 and 14 give the main effect plot and interaction plots for watermelon seeds. The trend for the main effect is similar to that of cactus pads, but the efficiencies are higher compared to that of cactus pads. Removal efficiency increased when all factor levels were increased. The main effect plot for particle size indicates an increasing trend of turbidity in water from 250 µm to 400 µm, followed by a decreasing trend from 400 µm to 630 µm. This suggests that smaller particle sizes are associated with lower turbidity removal efficiency. Additionally, the largest particle size shows the highest removal effectiveness. This implies that bigger particles were more easily eliminated as they settled more rapidly. The settling time plot indicates that longer durations of settling result in decreased turbidity levels and greater clarity of the water. Coagulant dosage had a significant effect as shown in Table 6. The lack of fit signifies the need for further research on optimizing these parameters.

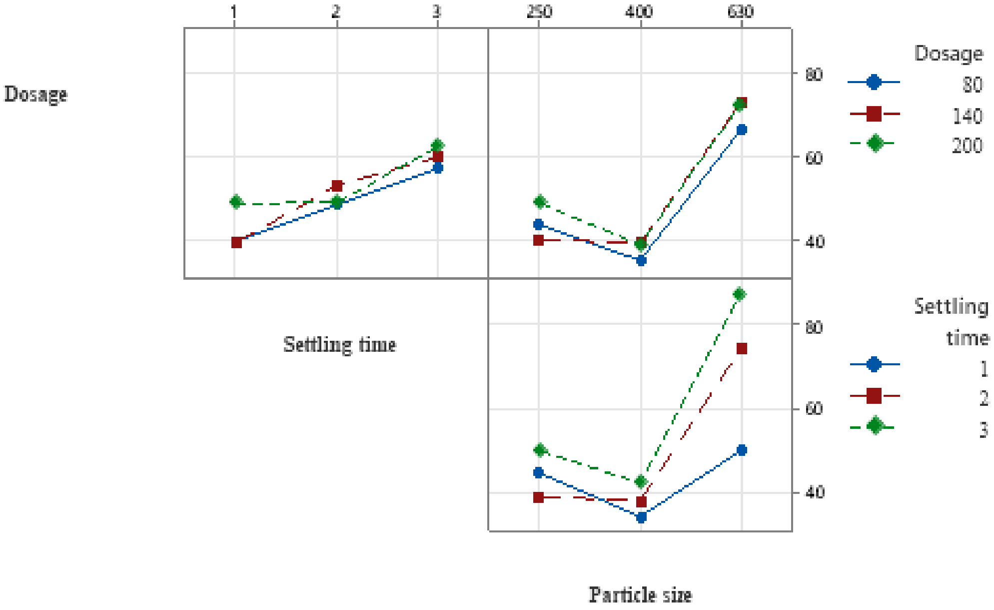

Figure 12: Main effect plot for turbidity retained while using watermelon seeds coagulants.

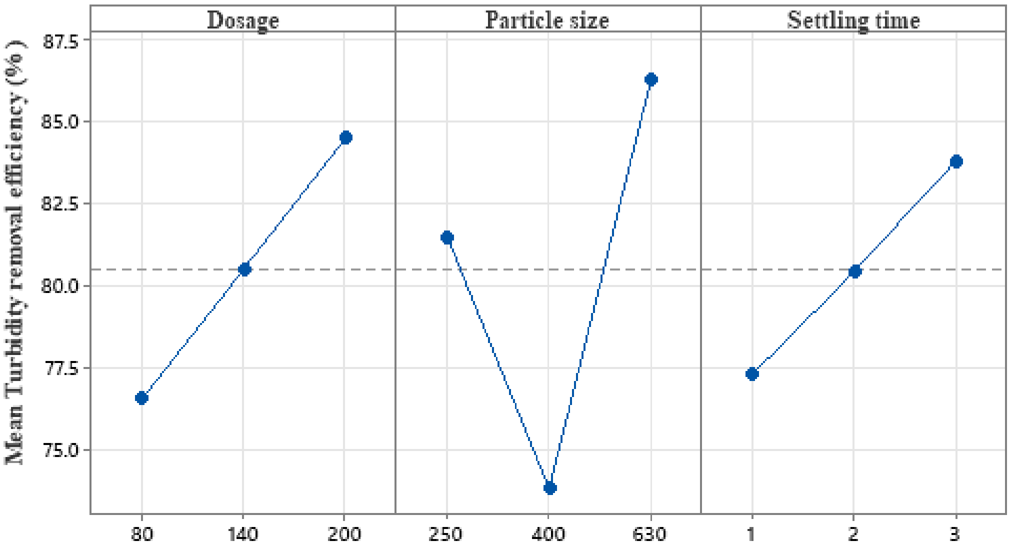

Figure 13: Main effect plots for turbidity removal % while using watermelon seeds coagulants.

Table 6: Analysis of Variance for Dosage and settling time when watermelon seed were used

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dosage	2	283.06	141.532	3.41	0.051
Settling time	2	189.70	94.850	2.29	0.125
Error	22	912.95	41.498		
Lack-of-Fit	4	36.73	9.182	0.19	0.941
Pure Error	18	876.22	48.679		
Total	26	1385.71			

The interaction effect between dosage and settling time is weak (Figure 14); however, removal efficiency was better when higher dosage and settling time were used. Slight interactions were observed between dosages and settling time when higher levels were used, giving an optimal removal efficiency of 92% when 3 hours of settling time was used. Increased dosage of watermelon seeds improved the performance of coagulants. Oil extraction from the coagulants during the preparation process was a challenging task hence not considered in this study. The presence of oil in coagulants tends to prevent coagulants from interacting with colloidal particles to form flocs. Therefore, further research should be done to determine the fulfillment of these natural coagulants for their application in industry.

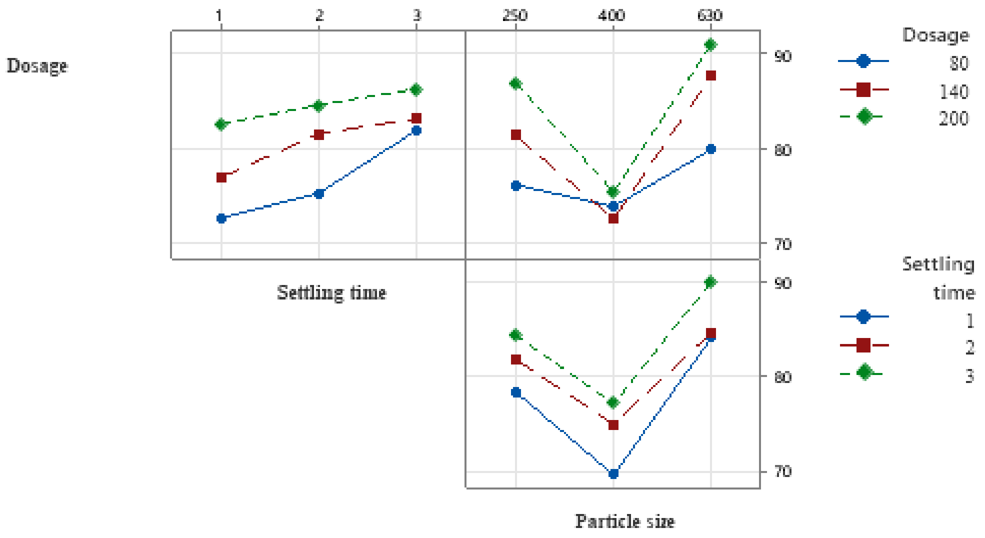

Figure 14: Interaction plots for turbidity removal while using watermelon seeds coagulants.

Watermelon seeds availability

After preparation, 500 g of watermelon seeds produced 22.6 g for 630 µm, 19.8 g for 400 µm, and 21.4 g for 250 µm, with an optimal dosage of 200 mg/L for both coagulants. This means that 1 m^3 of industrial effluent requires 4.424 kg of watermelon seeds for treatment daily. The production of wastewater for a textile industry was 2000 m^3 per day, requiring just 0.4 tonnes of coagulants. The watermelon fruit may generally produce up to 200 seeds and weighs roughly 4 kg. The weight of seeds varies; however, the approximation is that each weigh 52 mg. As a result, one ton of watermelon fruits can yield up to 2.6 kg of seeds. Tanzania produced 41,747 tons of watermelon in 2019 (Dijkxhoorn *et al.*, 2023) equivalent to 108.5 tonnes of watermelon seeds. This demonstrates the availability of raw materials for natural coagulants.

CONCLUSION AND RECOMMENDATIONS

Cactus pads and watermelon seeds both contain amino groups (-NH_2), hydroxyl groups (-OH), and carboxyl groups which promote coagulation. The cactus pads and watermelon seeds displayed a negative zeta potential due to functional group ionization, implying that they could act as natural coagulants. Watermelon seeds showed 92% removal efficiency at 200 mg/L, while cactus pads had 92% at 140 mg/L. When 200 mg/L of cactus pads was used, turbidity removal efficiency was only 88%. The main effect plot for particle size for both cactus pads and watermelon seeds demonstrated an increasing pattern from 250 µm to 400 µm, followed by a decreasing pattern from 400 µm to 630 µm. This implies that larger particles have a greater tendency to settle, can be easily removed, and hence have the highest removal effectiveness. The combination of cactus pads and watermelon seeds was found to be significantly more effective in reducing turbidity in wastewater from industries, with a clearance rate of approximately 94%. The maximum efficacy in removing turbidity was observed after a settling period of three hours. This finding indicates that the extended duration allowed a sufficient amount of suspended materials to settle. Additionally, this work has contributed to the limited amount of information in the literature about the effectiveness of these two natural coagulants in treating wastewater from the textile industry. Utilizing natural coagulants for treating industrial wastewater can decrease reliance on synthetic coagulants, which have negative environmental impacts and pose significant health risks.

Further studies are recommended to optimize coagulant dosage and settling time for cactus pads and watermelon seeds, and their synergetic effect when combined. Oil extraction from the coagulants during the preparation process was a challenging task. Therefore, much attention should be given to obtain oil-free powdered coagulants. Nevertheless, during the preparation process, both cactus pads and watermelon seed oil can be removed by using other methods like the Soxhlet apparatus. The presence of oil in coagulants lowers the efficiency of materials as oil tends to prevent coagulants from interacting with colloidal particles to form flocs. Therefore, further research should be done to determine the fulfillment of these natural coagulants for its application in industry.

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