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Comparison of natural extract as a clean coagulant with alum and natural extract-alum hybrid coagulant for removal of water turbidity

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ABSTRACT

In this study, the potential of natural coagulants such as plant extracts of *Cichorium intybus* (Ci), *Cichorium pumilum* (Cp), and *Cichorium endivia* (Ce) was investigated for removal of water turbidity. For conducting this study, distilled water and salts of KNO_3, $NaNO_3$, NaCl, and KCl were used to prepare the extracts, and parameters such as the turbidity removal percentage, the optimal concentration of plant extracts, the type of extracted extracts, pH, the amount of total dissolved solids, hardness, alkalinity, chloride, and sulfate were examined before and after the coagulation process. In this study, after determining the efficiency of different coagulants in removing turbidity from turbid water, the performance of the extracts was compared with the conventional chemical coagulant of aluminum sulfate (alum). The highest turbidity removal efficiency among different extracts was related to the use of *Cichorium intybus* extract; the high levels of protein and amine in this extract were proved by ninhydrin and Fourier-transform infrared spectroscopy tests. After determining the best plant extract (*Cichorium intybus* species extract), the hybrid coagulant was prepared using *Cichorium intybus* plant extract and alum (Ci/alum) in ratios of 1:1, 1:2, and 2:1, and its potential was also studied. The results showed that increasing the coagulant concentration to an optimal level is associated with an enhancement in turbidity removal efficiency. However, increasing the coagulant concentration to levels higher than the optimum value does not affect turbidity removal efficiency, and the removal efficiency remains almost constant. The maximum turbidity removal efficiencies using Ci, alum, and hybrid Ci/alum (1:1 ratio) were 92%, 90%, and 98%, respectively, which indicates the higher efficiency hybrid coagulant in the removal of turbidity from aqueous media. The results also showed that the use of 1 M NaCl solvent for the extraction of coagulants is more effective compared to other solvents used in this study.

Keywords: Plant extract; Natural coagulant; Coagulation; Turbidity; Efficiency; Hybrid

1. Introduction

Turbidity is caused by the presence of suspended and colloidal particles in water. Turbidity is one of the most imperative parameters to determine the efficiency of water treatment plant units and is also indicative of the quality of treated water. The most efficient method for removing turbidity in water treatment stages is coagulation and flocculation processes, followed by settling and filtration processes [1]. The coagulation process has always been an essential step in neutralizing the charge and destabilizing colloidal particles, natural organic matter, microorganisms, mineral

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ions, metals, and other contaminants in water [2]. Common coagulants in water treatment plants include chemicals such as aluminum sulfate (alum), ferric sulfate, aluminum chloride, and ferric chloride, of which alum is the most widely used. The use of chemicals as coagulants in drinking water treatment has disadvantages such as the problem associated with disposal of precipitated sludge, relatively high cost of preparation of chemicals, and the presence of chemical residues in the treated water, which is led to reducing water quality, impact on public health, and the risk of Alzheimer's disease in consumers of water treated with alum. These factors limit the use of chemical coagulants [3–6]. Another coagulant used for removal of turbidity from water is electric coagulants. These coagulants include pairs called electrodes in which reactions occur simultaneously at the anode and cathode; these electrodes need to be replaced early due to hydrolysis and maintenance of coagulation efficiency [7].

Given the disadvantages and disadvantages of chemical and electric coagulants, researchers are looking for alternative methods and materials to remove turbidity from the water that has the least adverse effects on human health and the environment. One of the alternative materials that have attracted a lot of attention today is the use of natural coagulants derived from plants, which not only do not have the disadvantages of chemical coagulants but also are environmentally friendly and easily decomposed in the environment. Such natural coagulants produce 20% to 30% less sludge than chemical coagulants such as alum, and on the other hand, the release of such sludge into the environment has no adverse effects on the environment [8]. The literature reviews show that many studies have been employed the coagulation process with chemicals to remove various contaminants such as toxins and pesticides [9–12], metal contaminants [13–15], anionic surfactants [16], and sodium lauryl sulfate [17]. However, few studies have been performed to evaluate the effectiveness of plant extracts in removing contaminants from drinking water. Therefore, due to a large number of studies on chemical coagulants and the adverse effects of such coagulants, as well as the benefits of natural coagulants such as cheapness, availability, locality, biodegradability, and compatibility of living organisms, it seems that research in the field of use and the evaluation of the effectiveness of such natural coagulants is necessary [18–20]. The plants used in this study are *Cichorium intybus* (Ci), *Cichorium pumilum* (Cp), and *Cichorium endivia* (Ce). These plants belong to the *Cichorium* genus and the Asteraceae family. The growing areas of these plants are so vast; so that they grow abundantly in Europe, Africa, and Asia. Due to the usefulness of these plants, their consumption has been common among the natives of different regions from the past to the present. In the chemical analysis of this plant, the presence of protein has been confirmed [21–23]. The study conducted by Al-Snafi [24] showed that plants of the *Cichorium* genus contain compounds such as proteins, flavonoids, and sugars. The presence of protein in the plant is one of the most important factors, which introduces it as a natural coagulant to remove the turbidity of aqueous solutions. Among different species of *Cichorium*, Ci, Cp, and Ce species are abundantly found in Iran and can be used in various fields. Due to this fact that no study has been yet done on the coagulation of pollutants by the natural coagulant of *Cichorium* plants, in present study, the extracts of Ci, Cp, and Ce species were used as natural coagulants to remove turbidity from aqueous solutions and then the performance of these plants was compared with alum coagulant and then with the alum-extract hybrid. In addition, the effect of pH parameters, plant extract dose, and the type of salt used to prepare the plant extract was investigated.

2. Materials and methods

2.1. Preparation of coagulants

All chemicals used in this study were purchased from Merck Company, Germany. To prepare plant extract as a natural coagulant, Ci, Cp, and Ce plants were collected from the eastern regions of Iran and transferred to the laboratory. In the laboratory, the aerial parts of the plant were separated by hand, dried at room temperature, and then crushed by a mill. Distilled water and various salts (e.g., NaCl, KCl, $NaNO_3$, and KNO_3) were used to prepare the plant extract. To prepare the plant extract, 2 g of powder obtained from each plant was added to 100 mL of distilled water and a solution containing each of the salts, and the mixture was stirred for 30 min using a magnetic stirrer. The resulting suspension was filtered with Whatman paper No. 42. The filtered solutions were used as coagulants and compared with each other. Also, a 2% alum stock solution was prepared by adding 2 g of alum powder ($Al_2(SO_4)_3{\cdot}18H_2O$) to 100 mL of distilled water. After determining the most effective plant extract as coagulants, to study the hybrid effect of plant extract and alum, the *Cichorium intybus* plant extract and alum (Ci/alum) with ratios of 1:2, 1:1, and 2:1 were prepared by suitable mixing plant extracts and alum [25–27].

2.2. Preparation of turbid water

For the coagulation process, turbid water was prepared by adding Iranian clay (used to make ceramics) to 1 L of distilled water. To achieve uniform dispersion of clay particles in distilled water, the clay suspension was stirred for 2 h using a magnetic stirrer. Then, to complete the hydration of clay particles (complete mixing of water and clay), the resulting suspension was left at room temperature for 24 h, and after 24 h, the supernatant was used to prepare turbid water with different turbidity (50–500 NTU). To investigate the effect of pH on turbidity removal efficiency, the initial pH of turbid water was adjusted to the desired values (2–12) with 1 M NaOH or HCl solution before the coagulation process. The pH of turbid water treated with natural coagulants separately was set in the neutral range [26].

2.3. Coagulation experiments

In this study, coagulation, flocculation, and sedimentation processes were performed in the standard Jartest device (VELPScientifica, Model: JLT6, Italy), which had six 1,000 mL beakers. Each beaker was filled with turbid water containing different turbidities. After conducting initial experiments and determination of concentration range, different extracts, alum, and Ci/alum hybrids were added separately to beakers. To perform the coagulation process, beakers were stirred by rapid mixing at 120 rpm for 2 min, and then, for the flocculation process, the mixing speed was reduced to 40 rpm and mixed for 20 min. After the coagulation and flocculation process, beakers were laid to rest for sedimentation of the flocs formed in the resulting suspension. After 30 min, clear samples were collected from the top part of the solutions and their residual turbidity was measured using a turbidimeter (Hach Turbidimeter Model 2100N), and the turbidity removal efficiency was calculated using Eq. (1) [26,27].

$$\eta = \left[\frac{\left(C_0 - C\right)}{C_0}\right] \times 100 \quad (1)[26,27]$$

where C_0 is the concentration of turbidity before coagulation and C is the concentration of turbidity after coagulation and sedimentation. In addition to determining turbidity, the concentration of soluble solids was estimated according to standard methods [25]. To investigate the effect of pH on turbidity removal, the pH of the solution was changed from 2 to 12. All experiments were performed at laboratory temperature (21°C ± 2°C), and for more useful results, the experiments were performed in duplicate and the average results were presented [26]. Also, the chemical properties of the used water including total dissolved solids (TDS), hardness, alkalinity, chloride, and sulfate were investigated before and after using the optimal dose of natural coagulant and coagulation test (Table 1).

2.4. Ninhydrin test

Determination of the quantity of primary amines in the Ci, Cp and Ce was carried out by ninhydrin test. This test was fulfilled based on below procedures:

2.4.1. Preparation of the reagents

At first, for preparing the ninhydrin color reagent, a certain amount of required chemicals (10 g of $Na_2HPO_4 \cdot 12H_2O$, 6 g KH_2PO_4, 0.5 g ninhydrin, and 3 g fructose) were dissolved in distilled water (1,000 mL). The prepared solution were then poured in a dark bottle and placed in a refrigerator at 4°C. After that dilution solution was prepared by dissolving a certain amount (2 g) of potassium iodate (KIO_3) in 600 mL distilled water and adding 400 mL 96% ethanol.

2.4.2. Preparation of the standard APTES solution and plotting the standard curve

At first, we diluted APTES (0.1 mL) to 10 mL using distilled water. It was then used for the preparation of four working sample tests (0.3, 0.5, 0.7, and 1 mL). Using distilled water, the samples were diluted to 10 mL. 2 mL of them were poured to the test tubes, and the ninhydrin color reagent solution (1 mL) was then added. After sealing the tube, it was placed in boiling water bath for 16 min. Instantly, they were cooled through immersion in a water bath for 20 min at 20°C. Then, the dilution solution (5 mL) was added, and the tube was prepared to read its absorbance by a spectrophotometer at 570 nm. The standard calibration curve was prepared by drawing the values of absorbance against the APTES concentration (Fig. 2).

2.4.3. Determination of amine concentration

After dispersing 3 mg of Ci, Cp, and Ce samples into 100 mL distilled water, the resulting suspension (2 mL) was poured into the test tubes. The ninhydrin color reagent solution (1 mL) was then added and the resultant mixture was mixed. After that, the tube was boiled in a boiling water bath (for 16 min). The change in solution color to purple–blue, which was observed after boiling is related to the reaction between the amino groups and the hydrated ninhydrin. The tube should be immediately cooled, which was done by immersing them in a water bath (for 20 min at 20°C). Finally, dilution solution (5 mL) was poured into the mixture and manually mixed, and the rate of sample absorption was then determined. Then, using the equation obtained from the standard curve (Fig. 2), the concentration of total amines in the studied extracts was calculated [27].

2.4.4. Fourier-transform infrared spectroscopy test

After determining the highest amount of amine among the studied plants, Fourier-transform infrared spectroscopy (FTIR) was utilized to determine the important functional groups in the structure of the most effective extract. This analysis was determined in the range of 4,000–500 nm. Sample preparation for analysis was performed using the

Table 1
Turbid water parameters before and after treatment

	Ci		Alum		Hybrid Ci+alum	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
TDS, mg/L	580	185	510	172	535	120
Alkalinity, mg/L	210	140	192	155	180	126
Hardness, mg/L	280	205	272	211	294	175
Chloride, mg/L	90	85	98	73	88	62
Sulfate, mg/L	165	130	170	125	180	102

Ci: *Cichorium intybus*, optimum dose 200 mg/L

KBr pellet method. The spectrum obtained from the Fourier transform was obtained and the peaks were analyzed (Fig. 3) [28].

3. Result and discussion

3.1. Effect of coagulant concentration

One of the most important parameters affecting the coagulation and flocculation process is the optimal concentration of used coagulant because the concentrations lower or higher than optimal values may lead to poor performance of the coagulation–flocculation process. Therefore, determining the optimal concentration of coagulant is very necessary for minimizing costs and achieving maximum efficiency in water treatment.

Fig. 1 shows the effect of the concentration of used natural coagulants on turbidity removal efficiency. This figure shows that the turbidity removal efficiency is significantly affected by the concentration of coagulants. When the concentration of Ci was increased from 25 to 200 mg/L, the turbidity removal efficiency was increased from 20% to 92%, and then the turbidity removal efficiency remained constant as the coagulant concentration was increased. The main mechanisms in the process of coagulation by plant extracts are adsorption, charge neutralization, and bridging between particles. Documented evidence shows that cationic proteins of the plant and turbidity particles with negative charges mostly treat water by neutralizing the charge. The study of Dalvand et al. [27] showed that the extract of the *Moringa stenopetala* plant (a dose of 240 mg/L) has the ability to remove 98.5% of dye from aqueous solution. The study of Hussain et al. [29] showed that the use of pine cone extract (a dose of 0.5 mL/L) removes turbidity up to 82%. Regarding the use of plant extracts for wastewater treatment, the study conducted by Prodanovic et al. [30] reported that bean extract with a dose of 5 mL/L is able to remove 68.8% of organic matter from wastewater. The study of Abood et al. [31] clarified that the seed extracts of peanut and sesame plants (with doses of 20 and 60 mg/L, respectively) have a turbidity removal efficiency of 88.3% and 79.7%. Bazrafshan et al. [32] indicated that the highest turbidity removal efficiency by *Pistacia atlantica* extract (dose of 0.4 mL/L) was 97.43%. Alenazi et al. [33] showed that the extract of *Strychnos potatorum* seed at a dose of 40 mg/L has a turbidity removal efficiency of 93%.

Fig. 1 also shows that Ci species extract has a higher removal efficiency compared to Cp and Ce species extracts. The higher removal efficiency by Ci can be attributed to the higher protein concentration in Ci extract, which was confirmed by the results of ninhydrin and FTIR tests (Figs. 2 and 3). Therefore, for conducting further studies, Ci extract was used as a more effective coagulant, and the effective factors were examined using Ci extract. Asrafuzzaman et al. [34] conducted a study on different extracts and observed that under the same conditions, different extracts have different turbidity removal efficiency; they also found that the extract of the *Cicer arietinum* plant has higher efficiency compared to *Dolichos lablab* and *Moringa oleifera*. However, in another study, Muthuraman and Sasikala [35] showed that *Moringa oleifera* plant extracts could represent higher turbidity removal efficiencies than *Strychnos potatorum* and *Phaseolus vulgaris* extracts. Al-Saati et al. [36], by studying two coagulants, that is, cactus and okra, proved that these coagulants have similar flocculation and coagulation properties and are suitable for removal of turbidity.

Fig. 1 also shows that with increasing the dose of alum to 200 mg/L, the turbidity removal efficiency increases to 90%; however, with further increase in the amount of alum, the turbidity removal rate does not change. This figure shows that increasing the coagulant dose does not cause restabilization and destabilization of flocs, and thus the removal efficiency is constant with changes in coagulant dose, which can indicate the predominance of the sweeping mechanism.

3.2. Ninhydrin test

Ninhydrin test was performed to determine the amines in the plant extract. Through using of this test, the absorption rates using a spectrophotometer (reaction of amine groups in the sample with ninhydrin dye reagent) were obtained to be 0.92, 0.74, and 0.62 for Ci, Cp, and Ce extracts,

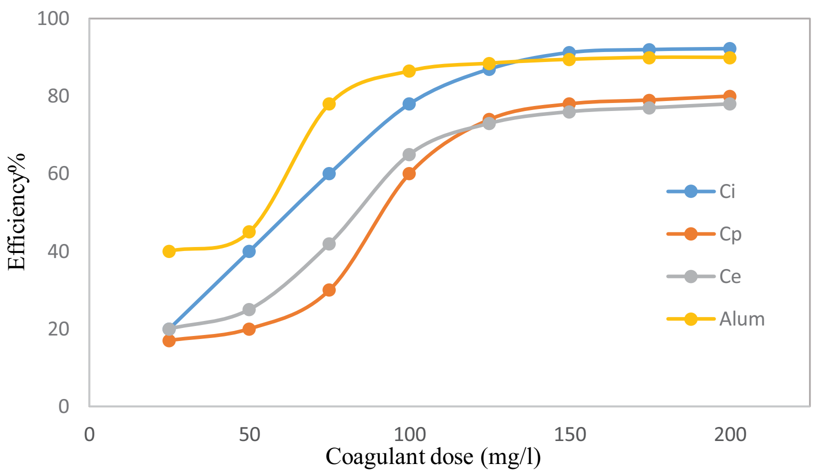

Fig. 1. Effect of coagulation dose of natural coagulants on turbidity removal (turbidity: 500 NTU, pH = 7). Ci: *Cichorium intybus*; Cp: *Cichorium pumilum*; Ce: *Cichorium endivia*.

respectively. Using the equation obtained from the standard curve (Fig. 2), the content of total amines in the samples was calculated, so that the amine concentrations in Ci, Cp, and Ce extracts were determined to be 0.63, 0.52, and 0.45 mmol/L, respectively. In a study conducted by Dalvand et al. [27], the uptake of amine groups with the ninhydrin dye reagent for *Moringa stenopetala* and *Moringa oleifera* were 0.8 and 0.68, respectively, and finally, using the standard curve equation, they have reported that the total concentration amine in samples was 0.66 and 0.57 mmol/L, respectively. Narasimhan and Sathiyani [37] also used the ninhydrin test to determine the protein content of *Cucurbita maxima* seeds.

3.3. FTIR spectra of *Cichorium intybus* extract

Fig. 3 shows the FTIR spectrum of important functional groups influencing the coagulation process. The broad peak of 3,000–3,600 cm^{-1} belongs to the amine groups (N–H). In fact, the amines extracted from Ci play the role of polymer. In Fig. 3, the peak at 3,418.05 cm^{-1} is assigned to the stretching group of amines (NH). Gomare and Mishra [28] using FTIR test and phytochemical analysis of *Hibiscus rosa-Sinensis* L. plant extract showed that the peak at 3,368.7 cm^{-1} belongs to the amine group. The peak at 1,636.64 cm^{-1} belongs to the bending group of amines and the peaks at 487.45 and 619.15 cm^{-1} belong to amide III. Since N–H and amide III groups play an important role in synthesis of protein. Therefore, the appearance of such peaks in Fig. 3 confirms the presence of amino protein in the Ci plant extract. The peak at 1,636.64 cm^{-1}, in addition to the bending group of amines, belongs to the highly conjugated C=O group [38]. Ramavandi et al. [39] showed that C=O, OH^-, CH^-, and OCH_3^- groups can play a role in removing turbidity from surface water. The study of Bazrafshan et al. [32] exhibited that the proteins in the extract of *Pistacia atlantica* can have a positive effect on the process of coagulation and flocculation. The study conducted by Muthuraman and Sasikala [35] clarified that the reduction of water turbidity by the extract of the plant *Moringa oleifera* is due to the presence of proteins in plant extracts.

3.4. Effect of extract-alum hybrid

Fig. 4 shows the effect of simultaneous application of Ci and alum plant extracts in different ratios (Ci/alum ratios of 1:1, 1:2, and 1:2). As shown in the graph, when alum and plant extract were used simultaneously, the highest

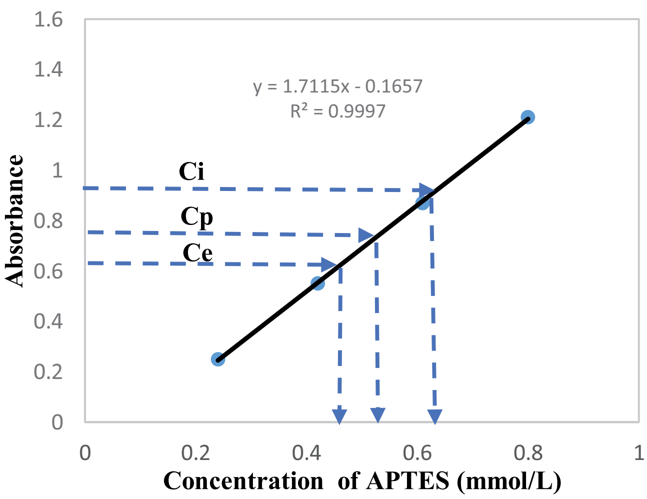

Fig. 2. Calibration curve for APTES concentration. Ci: *Cichorium intybus*; Cp: *Cichorium pumilum*; Ce: *Cichorium endivia*.

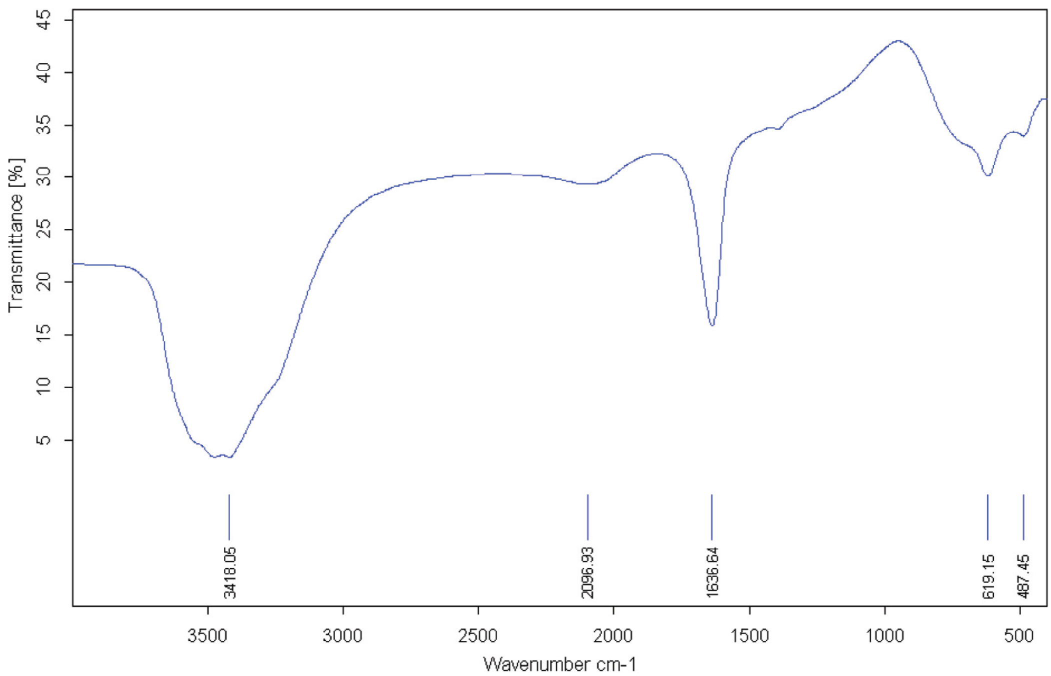

Fig. 3. FTIR spectra of *Cichorium intybus* extract.

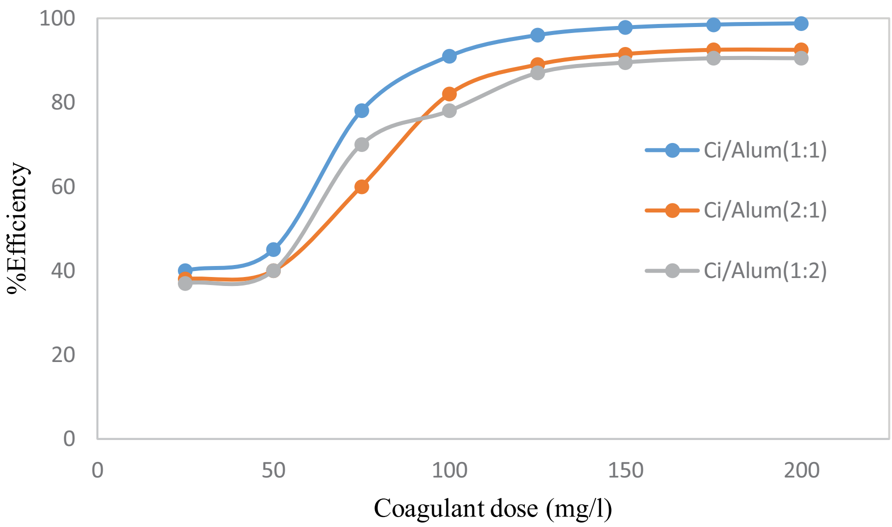

Fig. 4. Effect of hybrid coagulant dose on turbidity removal (turbidity: 500 NTU, pH 7).

turbidity removal efficiency (98%) was achieved at a concentration of 200 mg/L and a Ci/alum ratio of 1:1. However, in the ratios of 2:1 and 1:2, the removal efficiency decreases to 94% and 92%, respectively. Comparison of the coagulant concentration required to achieve maximum efficiency in Figs. 1 and 4 shows that when the plant and alum extracts are used simultaneously, the required coagulant concentration decreases. In water treatment plants, reducing the amount of coagulant consumption can offer a significant effect on reducing the amount of sludge produced in settling units of water treatment plant and greatly reduce the costs associated with sludge disposal.

Dalvand et al. [27] have stated that the reason for the employment of hybrid coagulants is the need to overcome the production of high sludge by alum and the need for high doses of natural coagulants for single use. Therefore, a hybrid coagulant has acceptable properties due to high coagulation properties, less sludge production, and more efficiency at lower doses. Therefore, the simultaneous application of natural coagulant with alum (Ci/alum) has properties such as high coagulation power, less sludge production, and higher efficiency at lower doses.

Table 1 shows the effect of Ci, alum, and Ci/alum coagulants on the chemical properties of water. As can be seen in this table, the simultaneous application of Ci and alum has more potential to remove the parameters including TDS, alkalinity, hardness, chloride, and sulfate, which may be due to the synergistic effect or the presence of proteins in the plant extract.

3.5. Effect of initial and final pH

Due to the fact that the pH parameter has an important effect on the coagulation–flocculation process through changes in the electrical charge of colloidal particles, the effect of pH on turbidity removal efficiency was also investigated in this study. Fig. 5 shows the effect of the initial pH of water on the turbidity removal by the Ci/alum coagulant. As shown in the figure, coagulation by Ci/alum hybrid with a ratio of 1: 1, in all pH range, has an efficiency of 98%, and pH changes do not have a significant effect on the performance of Ci extract and Ci/alum hybrid. However, the study conducted by Abood and Zhean [40] showed that pH has an important effect on coagulation by Mangosteen pericarp so that it removes 70% turbidity at pH of 4 and 98% at pH of 8. Also, studies conducted by Phani Madhavi and Rajkumar [41] showed that the highest turbidity removal efficiency is obtained by tamarind seed extract at pH = 8. The researchers reported that the effect of pH on turbidity removal is significant; thus, choosing a suitable pH is led to reduce coagulant consumption or increase turbidity removal efficiency. As shown in Fig. 5, when alum is used alone, the efficiency increases slightly by increasing the pH from 2 to 7. Nevertheless, by increasing from pH to 12, the efficiency decreases dramatically. In this study, the optimum pH was 7. Examination of changes in pH values after the coagulation and flocculation process showed that the final pH of the treated water did not change when the plant extract was used alone.

However, the use of alum and Ci/alum reduces the final pH of the treated water to about 4. The decrease in pH in the presence of alum and Ci/alum can be due to the hydrolysis of alum and the production of Al^{3+} and SO_4^{2-} ions in water; Al^{3+} reacts with OH^- or alkalinity, which is led to the consumption of alkalinity agents and the production of an acidic agent in water [42]. In water treatment plants, to prevent a sharp drop in water pH, alkalinity-causing agents, especially lime water, are added to the water, which produces more sludge in the sedimentation tank; disposal of such sludge is one of the most costly processes in the water industry. Therefore, if plant extract is used as a coagulant, the amount of sludge production can be significantly reduced, which will reduce the operating costs of water treatment plants.

3.6. Effect of initial turbidity

In this study, the effect of initial turbidity values on the coagulation efficiency of Ci, alum, and Ci/alum was investigated in the range of 50–500 NTU. The results showed that with increasing the initial turbidity, the turbidity removal

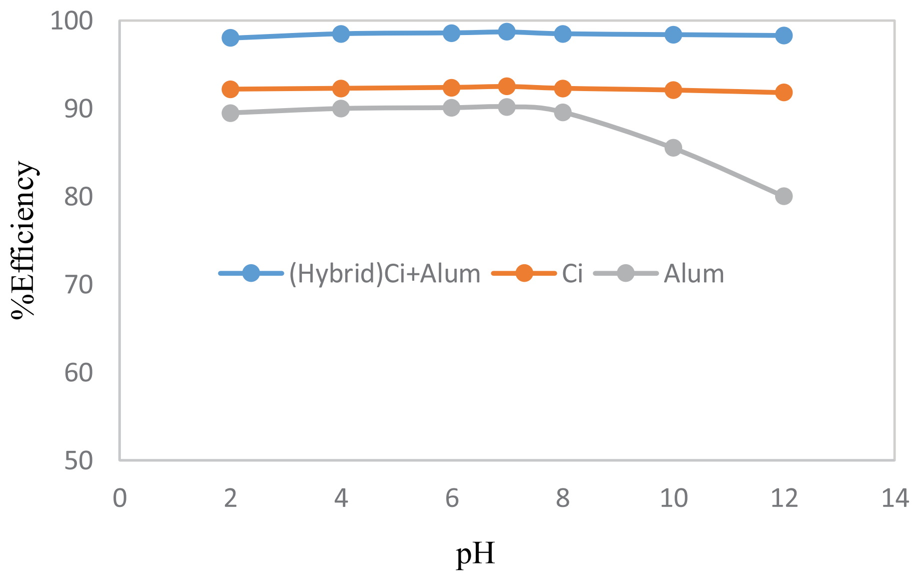

Fig. 5. Effect of pH on turbidity removal (Ci: *Cichorium intybus*, turbidity: 500 NTU, coagulant dose: 200 mg/L).

efficiency also increased, so that the removal efficiency for water with initial turbidity of 50 NTU using Ci extract was 20% and with increasing turbidity to 400 and 500 NTU, the removal efficiency increased by 84% and 90%, respectively.

For Ci/alum coagulant, the initial removal efficiency was 40% when the initial turbidity was 50 NTU. With increasing turbidity to 400 NTU, the removal efficiency increased to 94%. These results are consistent with the results of studies by other researchers who showed that increasing the initial turbidity of water increases the turbidity removal efficiency [43,44]. Considering that the initial turbidity of water was relatively high and no restabilization was observed by changes in the coagulation dose during the process, it can be concluded that the dominant mechanism in the coagulation process is the sweeping coagulation mechanism, which leads to trapping flocs in adsorbed particles.

3.7. Image of flocs

Observing the image of flocs using an optical microscope showed that flocs produced by Ci extract were larger and stronger than flocs produced by alum coagulant; however, it was less dense and smaller, and more fragile compared to flocs produced by Ci/alum hybrid (Fig. 6). Flocs produced by Ci/alum hybrid had high density, high strength, and high compaction (Fig. 6C). The high density, size, and compaction of the flocs lead to more sedimentation rate of them in the settling tanks. Dalvand et al. [27] have stated that the reason for the use of hybrid coagulants is to overcome the production of brittle and pinpoint flocs and have proposed the use of *Moringa* hybrid coagulant to increase the sedimentation rate of flocs.

3.8. Effect of salt and its concentration

Determining the type of solvent for the extraction of plant extracts containing proteins that are effective in removing turbidity is very important. In this study, for better extraction of plant extracts, various solvents such as DW, NaCl, KCl, $NaNO_3$, and KNO_3 were used. Among the above solvents, the solution containing NaCl salt had a better performance (Fig. 7). In addition to determining the type of solvent for plant extract extraction, determining the salt concentration in the solvent can also represent a significant effect on the quality of the extracted extract and thus, the turbidity removal efficiency. According to the studies conducted on removal of turbidity by plant extracts, in this study, different salts with different concentrations were used to extract the plant extract, among which NaCl with a concentration of 1M had a better efficiency (Fig. 8). Other researchers have used different solvents with different concentrations to obtain the plant extract, each of which has shown different results [1,30,31,35,45]. Therefore, it can be concluded that a type of salt with a certain concentration is required to extract any type of plant extract.

4. Conclusion

The general results of this study highlighted that the most important factor in a natural coagulant was the amount of amines in the plant extract. Ninhydrin and FTIR tests showed that the extract obtained from the Ci plant has the highest amount of amine, which increases the turbidity removal efficiency. The results of this study also indicated that the simultaneous use of Ci/alum is more efficient compared to the use of alum and Ci alone. The application of Ci/alum showed that in addition to removing turbidity, the chemical properties of water are also affected by its simultaneous application. The study of the effects of the initial pH of the solution displayed that the pH changes did not affect the coagulants of Ci and Ci/alum, which could lead to easy operation in water treatment plants. Examination of different solvents with different salts shows that NaCl has a better ability to extract Ci plant extract than other salts.

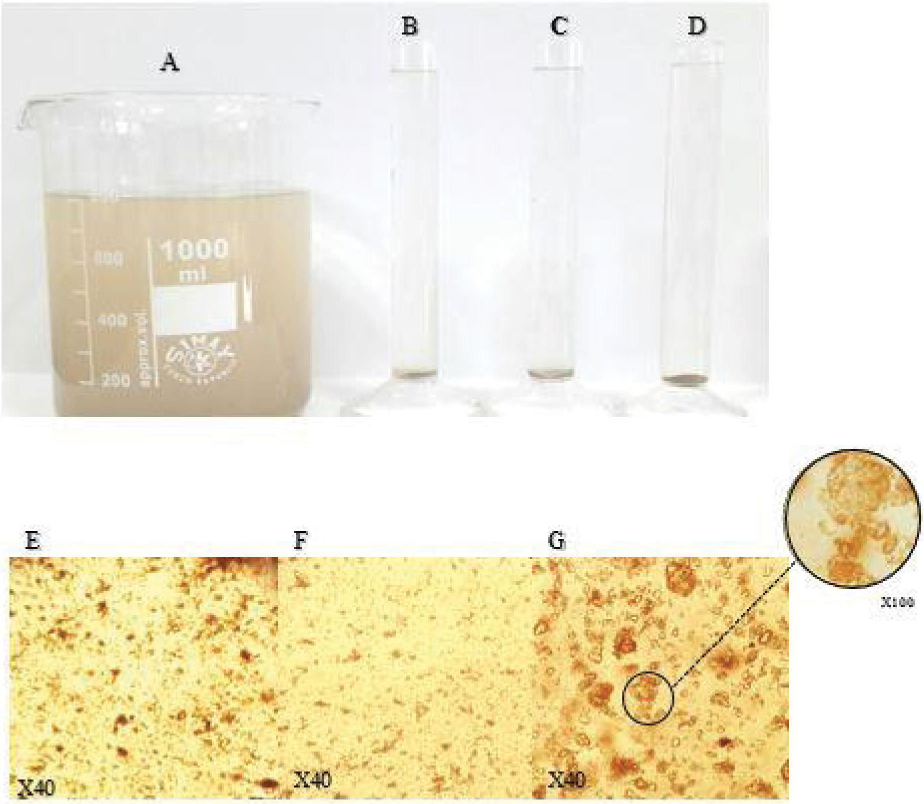

Fig. 6. Analysis of flocs due to natural and chemical coagulants (A) initial turbidity: 500 NTU, (B, E) *Cichorium intybus*, (C, F) alum, and (D, G) *Cichorium intybus*+alum.

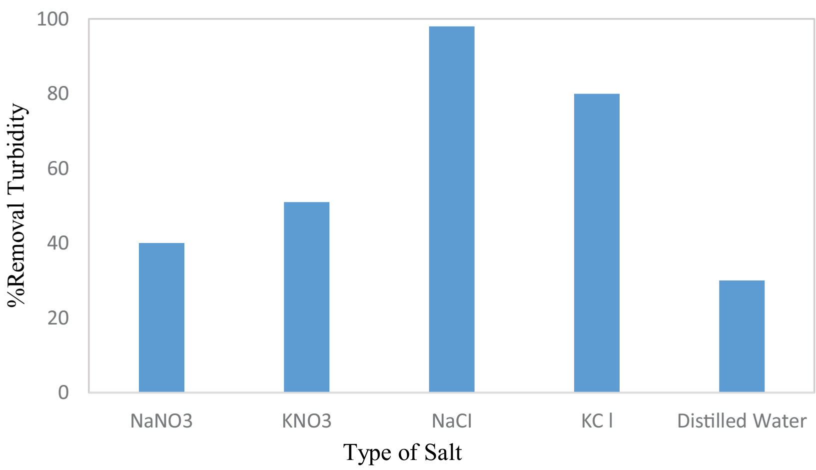

Fig. 7. Effect of type of salt used for coagulant extraction on turbidity removal (turbidity: 500 NTU, pH 7, salt concentration: 1 M, Ci dose: 200 mg/L).

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Author contribution

H.K. devised the project, the main conceptual ideas and proof outline. H.K. and S.M.M. carried out the experiment. S.D.A and H.A. processed the experimental data, performed the analysis and designed the figures. All authors discussed the results and contributed to the final manuscript.

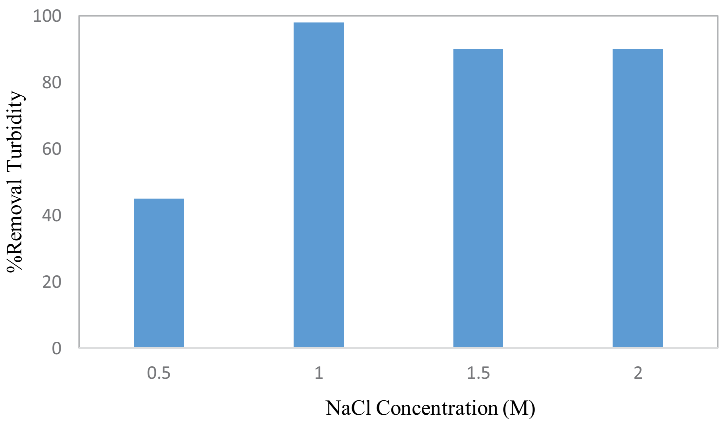

Fig. 8. Effect of NaCl concentration on turbidity removal (turbidity: 500 NTU, pH 7, Ci dose: 200 mg/L).

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