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Turbidity Removal Efficiency In Surface Raw Water Using Carica Papaya Seeds As Natural Coagulant

Sandy Vergara Marrugo[1], Jhon Jairo Feria Díaz[1], Eustorgio Amed Salazar[2]

[1]Faculty of Engineering, Universidad de Sucre, Colombia
[2]Faculty of Health Sciences, Universidad de Sucre, Colombia

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ABSTRACT

The purpose of this work was to evaluate the turbidity removal efficiency of Carica papaya seeds extracts as a natural coagulant for synthetic and river water samples. To achieve this objective, several jar tests were executed by applying different bio-coagulant dosages, at three concentration levels of raw water turbidity, according to standardized procedures. ANOVA was used to verify if there were statistically significant differences between the dosages applied, with a confidence level of 95%. High turbidity removals were achieved when the initial raw water concentration was equal to or greater than 200 ITU. Efficiencies of up to 90.7% were recorded for synthetic water samples, and 74.6% for river water when dosages of 50 mg/L were applied. It was shown that Carica papaya seeds extract has a high potential to be used efficiently in turbid water clarification.

Keywords: Raw water, Natural Coagulant, Papaya, Removal Efficiency, Turbidity

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1. INTRODUCTION

In the treatme.nt of drinking water, the clarification process or turbidity removal is very important. Many pathogens adhere and camouflage in the colloidal particles that cause turbidity and if these particles are not removed in the water, the pathogens can cause serious illness in people who ingest them for long periods of consumption (Chop et al., 2014). The unitary process that allows the turbidity removal in the water is called Coagulation. Generally, in water purification plants, chemical origin products are used as coagulating agents, among the most common are Aluminum Sulfate and Ferric Chloride, which are known to have several drawbacks both from consumers' health opinion and pollution to the environment (Amman et al., 2021a). Several studies have linked residuals of these chemicals as possibly responsible for adverse health effects such as Alzheimer's disease, dementia, and nervous system failure (Ahmad et al., 2016; Barakwan et al., 2019). Similarly, they are associated with environmental problems due to their toxicity in fish, freshwater algae, protozoa, and marine bacteria (Georges et al., 1995; Gutiérrez et al., 1998), as well as a wide variety of undesirable characteristics for fish. If soils are applied as soil improvers in agricultural land (Alvarenga et al. 2015; Upper et al., 2014). An alternative to chemical coagulants is coagulants from plant, animal, or microorganism sources reported in the technical literature for treating natural waters and wastewater (Headache et al., 2014). Several studies have shown the effective removal of turbidity in different water types with natural coagulants application obtained from Basil, Senna, Moringa and Bean seeds, from Cactus mucilage, from gums, from Acacia and Company bark and wood, among other plants and potential sources (Shamsnejati et al., 2015; Antov et al., 2010; Antov et al., 2012; Beltrán et al., 2011; Subramonian et al., 2014; Bhuptawat et al., 2007; Bathia et al., 2007; Martínez et al., 2003). However, it is the coagulating extracts produced with Moringa oleifera seeds that have shown higher turbidity removal efficiencies in raw water, like those obtained with aluminum sulfate (Rodiño et al., 2015; Feria et al., 2014; Shahzad et al., 2014). The application of biocoagulants in water treatment produces a lower volume of non-toxic and highly biodegradable sludge, in addition, it can eliminate the cost of buying and importing chemical products, since the raw materials for bio-coagulants can be obtained locally (Bello et al., 2020).

Recent studies conducted in Malaysia, India, and Nigeria have suggested that Carica papaya seeds have great potential as a promising bio-coagulant for the treatment of raw or polluted water (Amran et al. 2021a; George and Chandran, 2018; Eletta et al. al., 2017). Carica papaya, commonly known as papaya, has been a popular fruit around the world. It tends to grow in tropical or subtropical regions and its international trade has been reported to be worth almost US$200 million in 2009 (Amran et al. 2021a). The active coagulating agents of bio-coagulants are usually the content of proteins that compose it, they are responsible for the raw water clarification. The protein in the shelled Carica papaya seeds extract was present in a comparable concentration with other bio-coagulants such as Moringa oleifera, Chestnut, and Acorn. The registered protein content of the shelled Carica papaya seeds is 0.363 mg/mL, slightly lower than the protein content of the Quercus robur extract (0.540 mg/mL) and very similar to that of Moringa oleifera with an average of 0.371 mg/mL (Amran et al., 2021a).

The objective of this work was to find the turbidity removal efficiency of Carica papaya seeds extract when applied to synthetic water samples and raw water from a river and to verify its influence on the pH of the treated water.

2. MATERIALS AND METHODS

2.1 Water samples

The water samples used in the jar tests were of two types: synthetic water and raw river water. The synthetic water samples were prepared with gray kaolin, which was diluted in a container with 20 liters of tap water until the desired initial turbidity was obtained for each jar test. The raw water samples come from the Sinú River, in Monteria city, Colombia. The river samples were taken in punctual monitoring during the rainy season. All samples were stored in 20-liter plastic containers and transported to the University of Sucre in Sincelejo city from Colombia, where the jar tests were performed.

2.2. The coagulating extract preparation of Carica Papaya seeds

From the fruit of the Carica papaya tree, the seeds that were used for coagulating extract preparation were obtained. They were manually shelled and then dried by putting them in the sun for eight days at room temperature. The dry seeds were passed through a manual mill and sifted through a No. 40 mesh repeatedly until a very fine powder was obtained. Then 10.0g of the obtained powder was dissolved in a volumetric flask, up to 1.0 L with 1.0% (w/v) sodium chloride saline solution. The solution was mixed with magnetic stirring for 1 hour and vacuum filtered through cellulose filter paper. The filtrate was labeled as saline coagulant extract with a concentration of 10,000 mg/L and was kept refrigerated at 4°C until its application (Feria et al., 2016).

2.3 Jar Test

Carica papaya seeds extract was applied to each raw water sample as a coagulant, at dosages of 10, 20, 30, 40, and 50 mg/L. An EyQ F6-300-T brand jar test equipment equipped with six rotating blades and the same number of 1000 mL beakers was used. Fast mixing was at 200 rpm for 1 minute (speed gradient of 170 s-1), followed by slow mixing at 40 rpm for 20 minutes (speed gradient of 22 s-1) and with a settling time of 30 minutes (Feria et al., 2014; Standard ASTM D2035-08). Additionally, no dosage of the coagulating extract was applied to one of the containers to serve as a control or blank during the tests.

2.4 Equipment and Physicochemical Parameters

Turbidity and pH were measured in duplicate for all water samples before and after the jar tests. Turbidity was measured with a Thermo Orion AQ 3010 turbidimeter and pH with a SI Analytics-Lab865 pH meter. It is following the measurement protocols established in the standardized methods for drinking and wastewater analysis. It is, according to the American Public Health Association (APHA, 2005). The removal efficiency of each dosage applied to the water samples was calculated using equation 1 (Amran et al., 2021b):

$$\text{Turbidity removal (\%)} = \frac{\text{Initial turbidity} - \text{Final turbidity}}{\text{Initial turbidity}} \text{x}100. \qquad (1)$$

2.5 Experimental design

The experimental design used consisted of two factors statistical analysis (initial water turbidity and coagulant dosage) at various levels. The samples' initial turbidity was 50 NTU, 100 NTU, and 200 NTU, approximately, and the applied dosages of Carica papaya seeds coagulating extract were 10, 20, 30, 40, and 50 mg/L. The dosages were applied both to the samples of raw water from the Sinú River and to synthetic water-prepared samples in the laboratory. This design was made to determine the effect of each factor, that is, the change in the response (which in this case was the bio-coagulant removal efficiency) produced by a change in the factor level. The interaction between the factors and their effect on the system's response to the pH of the samples was also analyzed. The statistical tool that was implemented for data analysis corresponds to an analysis of variance (ANOVA), using the Statgraphics Centurion XVI program (Version 16.0.07). For all statistical analyses, a significance level of $p<0.05$ was established.

3. RESULTS

To verify whether the water type (synthetic or river) had any effect on turbidity removal in the jar tests, an ANOVA was performed to identify whether there are statistically significant differences between the removal efficiency results achieved when using each type of water. Figure 1 and Table 1 show the results obtained.

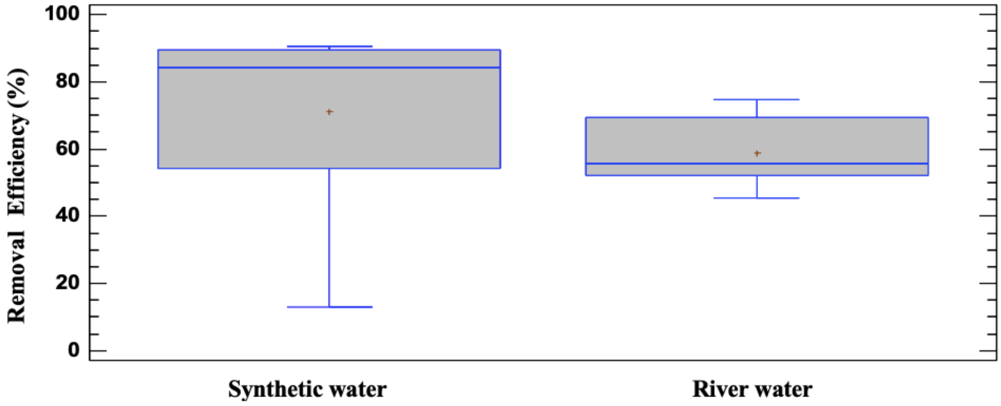

Figure 1: Boxes with whiskers of the different efficiencies obtained when river water and synthetic water were used

Table 1: ANOVA to compare removal efficiencies between the types of water used in the jar tests

Source	Sum of Squares	DF	Mean Squares	F-Value	P-Value
Between	1128.53	1	1128.53	3.02	0.0934
Within Groups	10476.7	28	374.168		
Total (Corr.)	11605.3	29			

Since the P-value of the F-ratio is greater than or equal to 0.05, there is no statistically significant difference between the average Removal Efficiency (%) in the middle of one water type and another, with a 95.0% confidence level. In other words, the Carica papaya seeds coagulant has the potential to remove turbidity in the water, regardless of whether it is prepared under laboratory conditions with gray kaolin or natural raw water from the Sinú River. However, Figure 1 shows that for synthetic water efficiencies of up to 90.74% were achieved in turbidity removal and for river water, only reductions of up to 74.63% were performed. Figures 2 and 3 show the removal efficiencies achieved from the initial concentration of synthetic and river water samples, respectively.

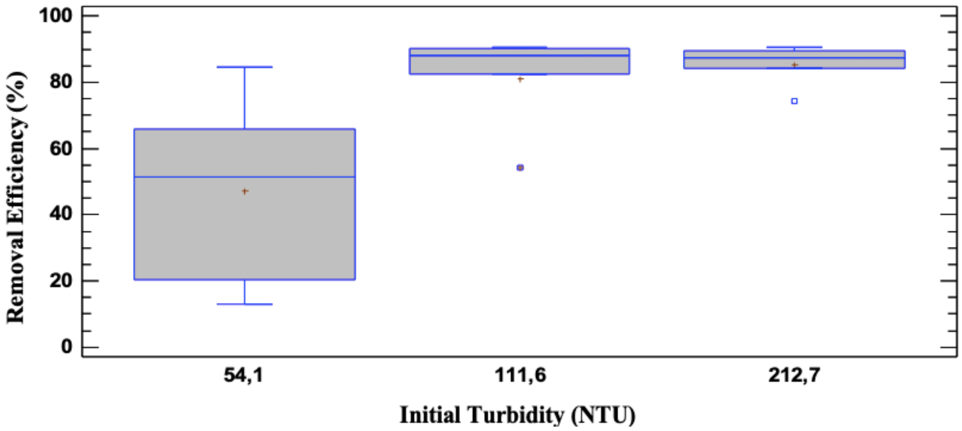

Figure 2: Removal efficiencies achieved for the three initial turbidity levels of the synthetic water samples

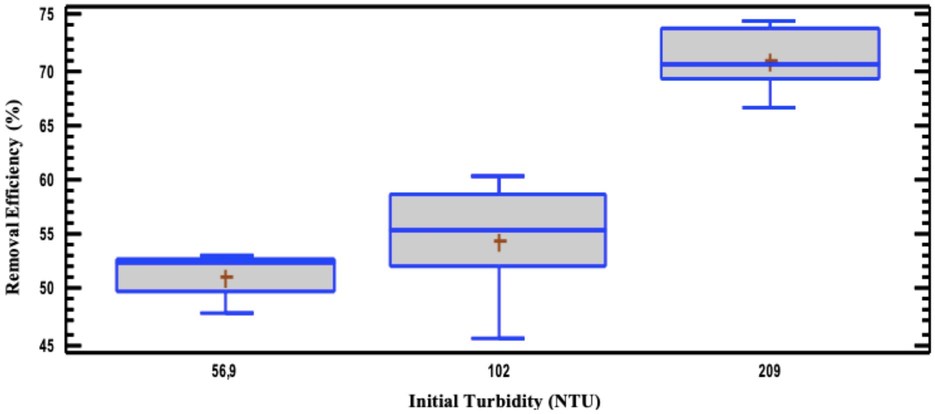

Figure 3: Removal efficiencies were achieved for the three initial turbidity levels of the water samples from the Sinú River.

According to what is shown in Figures 2 and 3, the best turbidity removals were achieved when the synthetic water turbidity was greater than 100 NTU, with removals greater than 80%, regardless of the applied dosage of coagulant. In contrast, for river water, the best removals achieved (between 70% and 75%) only occur when the initial turbidity of the water was 200 NTU. This behavior can be explained by the interference caused by the variety of colloids present in the Sinú River water samples, responsible for its turbidity.

To verify each dosage incidence in the treatment of the water samples, an ANOVA was executed for both the synthetic water and the river water. Figures 4 and 5 and Tables 2 and 3 show the results obtained.

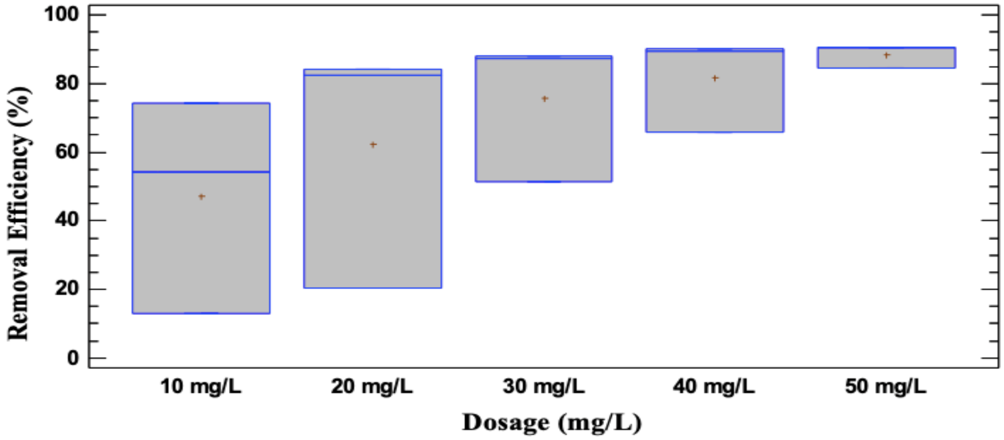

Figure 4: Removal efficiencies were achieved according to the dosages applied to the synthetic water samples

Table 2: ANOVA to compare turbidity removal efficiencies from coagulant dosages applied to synthetic water samples

Source	Sum of Squares	DF	Mean Squares	F-Value	P-Value
Between	3279.92	4	819.979	1.4	0.303
Within Groups	5863.43	10	586.343		
Total (Corr.)	9143.35	14			

In Figure 4 it is possible to observe that as the dosages put into the synthetic water samples increases, the variation in turbidity removal decreases. In this way, while for the applied dosage of 10 mg/L a range of removal efficiencies between 10% and 75% was obtained, for the dosage of 50 mg/L, the range was between 85% and 90%. This confirms what was found in Figure 2 when it was shown that the initial turbidity of the water plays a very important role in the coagulant efficiency for turbidity removal. On the other hand, according to what is shown in Table 2, since the P-value of the F-ratio is greater than or equal to 0.05, there is no statistically significant difference between the average removal efficiency between one dosage and another, with a 95.0% confidence level, that is, the removal efficiency does not depend directly on the coagulant applied dosage but rather on the initial synthetic water turbidity.

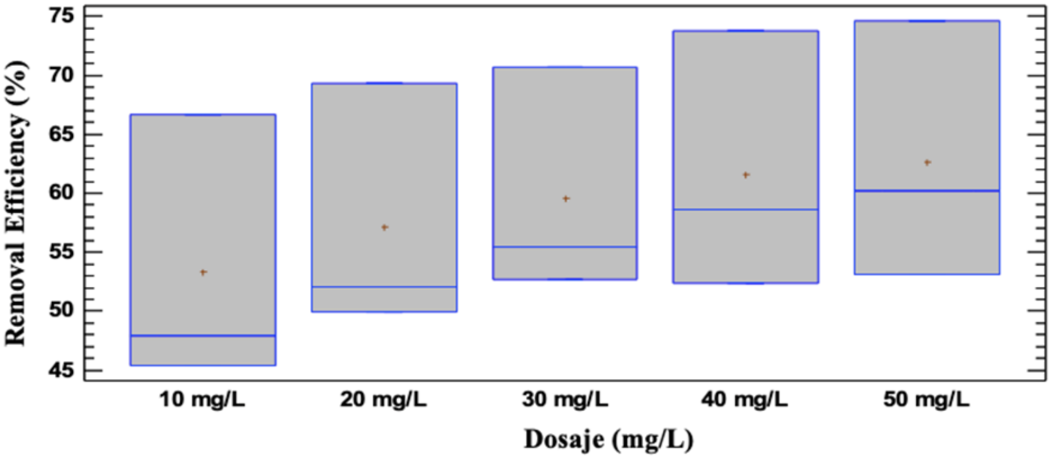

Figure 5: Removal efficiencies were achieved according to the dosages applied to the water samples of the Sinú River

Table 3: ANOVA to compare turbidity removal efficiencies from the dosages of coagulant applied to water samples from the Sinú River

Source	Sum of Squares	DF	Mean Squares	F-Value	P-Value
Between	167.46	4	41.865	0.36	0.8323
Within Groups	1166.52	10	116.652		
Total (Corr.)	1333.98	14			

According to what is shown in Figure 5, the tendency to achieve better efficiencies is still with the dosage of 50 mg/L, although it is not as marked as the tendency shown in synthetic water. These results are also validated by the ANOVA results shown in Table 3, since the P-value of the F-ratio is greater than or equal to 0.05, there is no statistically significant difference between the average Removal Efficiency between a dosage and another, with a 95.0% confidence level. As for synthetic water samples, the removal efficiency does not depend directly on the coagulant dosage applied, but rather on the initial turbidity of the river water. However, the higher marginal effectiveness of the higher dosages, compared to the lower dosages, can be attributed to the high positive surface charge of the coagulant. Thus, sufficient for the colloidal particles' destabilization of the raw water (Kakoi et al., 2016; Zaidi et al., 2019).

Figures 6 and 7 show the behavior of the pH after the different dosages application of coagulant to synthetic water and river water samples, respectively.

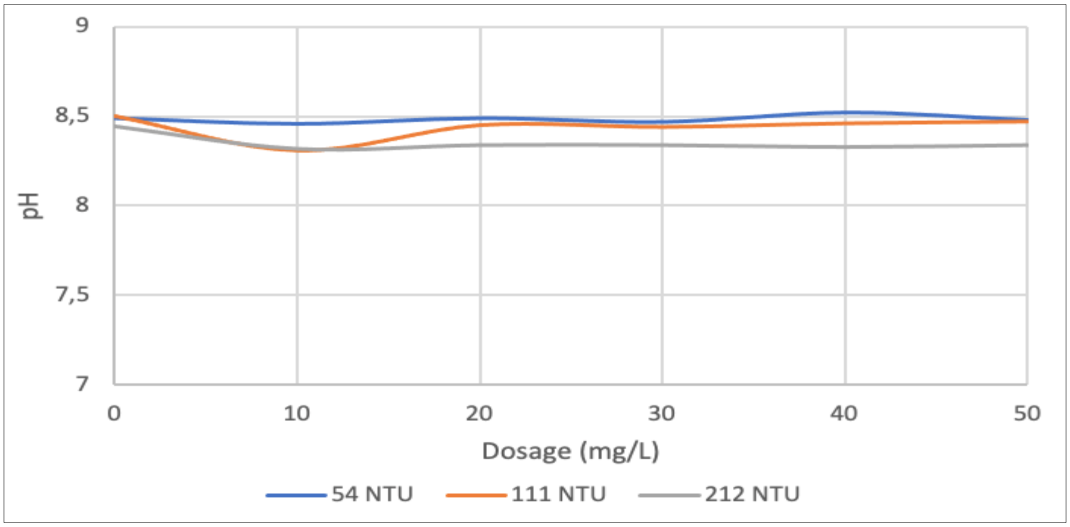

Figure 6: The pH behavior as a function of the coagulant dosages applied to the synthetic water samples.

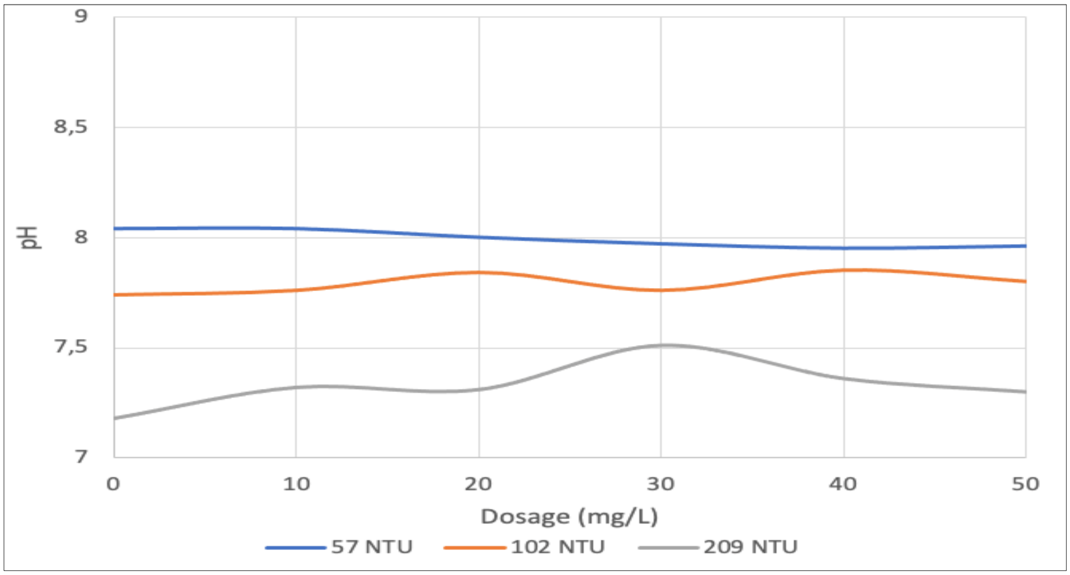

Figure 7: The pH behavior as a function of coagulant dosages applied to the water samples of the Sinú River

In the previous Figures, the turbidity values correspond to the initial turbidity of synthetic water samples (Figure 6) and river water (Figure 7), respectively. To verify if the different dosages applied to the water samples influenced the behavior of the pH, ANOVA was performed on the data groups found. Tables 4 and 5 show the results of the ANOVAs mentioned.

Table 4: ANOVA to identify statistically significant differences in pH after applying the coagulant dosages to the synthetic water samples

Source	Sum of Squares	DF	Mean Squares	F-Value	P-Value
Between	0,0201167	5	0,00402333	0,7	0,631
Within Groups	0,0685333	12	0,00571111		
Total (Corr.)	0,08865	17			

Table 5: ANOVA to identify statistically significant differences in pH after applying the coagulant dosages to the river water samples

Source	Sum of Squares	DF	Mean Squares	F-Value	P-Value
Between	0,0153167	5	0,00306333	0,03	0,9996
Within Groups	1,44793	12	0,12066100		
Total (Corr.)	1,46325	17			

Since the P-value of the F-ratio is greater than or equal to 0.05, there is no statistically significant difference between the mean PH from one dosage level to another, at a 95.0% confidence level. Similar results were reported by other authors, who demonstrated that the application of bio-coagulants does not alter the original pH of raw water (George et al., 2018; Feria et al., 2016; Rodiño et al., 2015). However, at pHs below 6, it is possible to increase the turbidity removal efficiencies of the water since the isoelectric point of colloids (negatively charged) is generally at low pH (Kristianto et al. 2018). Therefore, at an optimum pH above the isoelectric point, the colloidal particles will have a better reaction with the (positively charged) bio-coagulant particles (Amran et al., 2021). In this way, there is the possibility that both the charge neutralization coagulation mechanisms and the bridging between particles occur simultaneously in the removal of turbidity with this bio-coagulant type (Kara et al., 2008). Table 6 shows a synthesis of the best turbidity removal results achieved in the jar teas carried out in this work.

Table 6: Maximum turbidity removal efficiencies according to the type of water, pH, and applied dosage of coagulant from Carica papaya seeds

Type of water	Initial turbidity of raw water	Applied dosage (mg/L)	pH	Removal Efficiency (%)
Synthetic	212.7	50	8.5	90.73
Sinú river	209.0	50	7.2	74.60

The results show that the coagulant efficiency of Carica papaya seeds extract was higher in synthetic water samples than in river water samples, despite having very similar initial turbidities. This behavior can be explained due to the type of natural colloids that the Sinú river has and the possible interferences that they can cause in the coagulation mechanisms. However, similar results were reported by Amran et al., (2021) for synthetic samples (Initial Turbidity=500 NTU; Dosage= 50 mg/L; pH=3; Removal= 97%) and for river water samples (Initial turbidity=300 NTU; Dosage= 196 mg/L; pH=6; Removal= 87.3%), which demonstrates the coagulant effectiveness in the raw water treatment and its possibility of being used in purification systems as a replacement for chemical coagulants.

4. CONCLUSIONS

According to the results obtained in this study, the coagulant extracts of Carica papaya seeds have been shown to be promising new bio-coagulant to treat raw water from surface sources. Due to its low influence to alter initial physicochemical parameters of raw water, such as pH, it can be an efficient, environmentally friendly, and economical substitute for coagulants of chemical origin. However, its use is recommended in highly turbid surface waters (greater than 200 NTU) and with a pH close to 7 units. Due to many natural polyelectrolytes that this bio-coagulant has, it is possible to affirm that its coagulation capacity is like that of Moringa oleifera seed extracts.

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