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RESEARCH ARTICLE
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CLARIFICATION OF SURFACE WATER BY MEANS OF THE COAGULATING ACTIVITY OF GROUND FRUIT SEEDS OF TAMARINDUS INDICA L.

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ABSTRACT
The objective of this research was to evaluate the coagulating activity of Tamarindus indica L. seed powder dissolved in water and saline solution, compared to aluminium sulphate in the removal of turbidity from surface water of the Magdalena River (Colombia). Through the extraction of Tamarind seed powder, and performing a jar test, evaluating the percentage of removal in the different treatments, starting from surface water with initial turbidity of 172 NTU, 180 NTU, 215 NTU and 320 NTU. The tests showed removals of 86% and 87% with doses of 35 mg/L and 40 mg/L respectively for the solutions with NaCl 1.0 N and coagulant seed powder. From the above, significant differences between the coagulant solutions are evident, but not between the coagulant doses used, suggesting further tests to obtain the optimum doses within the coagulation-flocculation process.

Keywords: Biocoagulants, flocculation, turbidity, clarification.

INTRODUCTION
The treatment of surface water to make it drinkable is one of the most important processes for its access and consumption. In South American countries, water scarcity and its effects on the development of populations have been related to the availability and quality of water resources, the latter being one of the most important problems at a global level (van Vliet et al., 2021). Achieving sustainable development through clean water for all (United Nations [UN], 2018) implies the implementation of environmentally friendly treatment alternatives to improve water quality. Under this approach, there has been increasing research evaluating the use of natural coagulants in water treatment as substitutes for metal salts, metal hydroxides ($Al(OH)_3$ and $Fe(OH)_3$), as well as

polymerized inorganic coagulants (polyaluminium chloride / PAC) (Dayarathne et al., 2021) widely used in water treatment.
Among the natural coagulants, the active ones extracted from plants stand out, highlighting species such as Monringa oleifera Lam, Mussa L, Tamarindus Indica L, Opuntia stricta (Haw.) Haw. (Nhut et al., 2021; Hussain and Haydar, 2021 Zainol and Nasuha Mohd Fadli, 2020; Chitra and Muruganandam, 2019). Particularly the powder extracted from the seeds of Tamarind (*Tamarindus Indica L*) has been evaluated in the removal of turbidity and COD (Chemical Oxygen Demand) from water; as an anionic polysaccharide (Zainol and Nasuha Mohd Fadli, 2020), consisting of glucose, xylose and galactose, with the presence of -OH functional group and carboxylic acid in its chemical structure, which would be responsible for its coagulant activity (Zainol et al., 2021). Based on the evidence of the previous results, the present research aimed to evaluate the coagulating activity of Tamarindus indica seed powder dissolved in water and saline solution, compared to aluminium sulphates in the removal of turbidity from surface waters of the Magdalena River (Colombia).

MATERIALS AND METHODS

Extraction of Tamarindus indica seed powder and preparation of coagulant solutions. For the preparation of the coagulant powder from the Tamarind fruits, the following procedure was used: First of all, the husk and pulp were removed; the seeds obtained were dried at room temperature and then ground and passed through a sieve to obtain the appropriate size. For the preparation of the coagulant solutions, the powder was dissolved in distilled water and sodium chloride solution (NaCl 1.0 N) following the protocol proposed by Buelvas et al. (2020).
Jar test. For clarification, the jar test was used using the coagulation-flocculation process in an E&Q model FP4 flocculator. Samples of surface water from the Magdalena River at different turbidity were added to the coagulant solution and aluminium sulphate was used as a control. The treatments and the control were carried out in triplicate and were shaken at 100 rpm for 1 minute for fast mixing and at 40 rpm for 30 minutes for slow mixing, and then rested for one hour according to ASTM No. D2035-80.
Coagulant activity. *To evaluate the percentage of coagulant activity in the treatments measured by the reduction of turbidity from its initial values, the following equation was used:*

$$\% \, Coagulating \ activity = \frac{RT \ control - RT \ sample}{RT \ control} * 100$$

Percentage removal. The turbidity removal rate was determined using the following equation:

$$\% \, removal = \frac{Ti - Tf}{Tu} * 100$$

Experiment design. A 3x2x3 multifactorial design was carried out in which initial turbidity (172 NTU, 180 NTU, 217 NTU and 320 NTU) of the sample, 2 doses of coagulant and 3 coagulant solutions were evaluated. Statistical analyses were performed in Statgraphics centurion version XVIII.

RESULTS AND DISCUSSION

In the table 1 shows the results of the turbidity obtained after treatment with the coagulant solutions prepared with tamarind seed powder and distilled water.

Table 1. Final turbidity (NTU) results after treatment with seed powder solution in distilled water.

Initial turbidity of surface water (NTU)	dosage	Final Turbidity (NTU)
172	35 mg/L	65,6 ± 2,1
	40 mg/L	64,9 ± 1,5
180	35mg/L	63,1± 1,3
	40 mg/L	61,1 ± 0,6
217	35mg/L	71,1 ± 1,9
	40 mg/L	69,3 ± 1,9
320	35mg/L	70,2 ± 2,4
	40 mg/L	68,2 ± 1,7

The results obtained for turbidity after treatment with the coagulant solutions prepared with tamarind seed powder and saline solution are shown in table 2.

Table 2. Final results for turbidity (NTU) after treatment with seed powder in saline (NaCl 1.0 N).

Initial turbidity of surface water (NTU)	Dosage	Final Turbidity (NTU)
172	35 mg/L	47,1 ± 2,1
	40 mg/L	46,8 ± 1,1
180	35mg/L	47,1 ± 1,9
	40 mg/L	46,9 ± 4,2
217	35mg/L	49,1 ± 1,6
	40 mg/L	48,1 ± 1,8
320	35mg/L	44,2 ± 1,6
	40 mg/L	42,1 ± 1,8

Table 3 describes the turbidity results obtained after treatment using aluminium sulphate as coagulant.

Table 3. Final turbidity results (NTU) after treatment with Aluminium Sulphate solution

Initial turbidity of surface water (NTU)	Dosage	Final Turbidity (NTU)
172	35 mg/L	7,1 ± 0,7
	40 mg/L	6,5 ± 0,5
180	35mg/L	7,2 ± 0,6
	40 mg/L	6,2 ± 0,5
217	35mg/L	7,1 ± 0,6
	40 mg/L	7,0 ± 0,7
320	35mg/L	7,1 ± 0,6
	40 mg/L	6,7 ± 0,4

The results of turbidity removal and coagulant activity in the different treatments are shown in table 4.

According to the results in table 4, the removal percentages show the existence of significant differences in the treatments, with higher removal percentages in the solution composed of NaCl 1.0 N and coagulant seed powder, reporting a coagulant activity of 86% and 87% with doses of 35 mg/L and 40 mg/L respectively, in water samples with initial turbidity of 320 NTU. This coincides with that reported in the tests carried out by Zainol and Nasuha Mohd Fadli (2020) with removal percentages of 99.4% in tamarind seed powder solutions prepared with 1.0 M NaCl.

Likewise, in the tests carried out by Zainol et al. (2021) the coagulant solutions were prepared at different doses in the solvents sodium chloride and distilled water, and additionally a solution with potassium chloride; for these solutions the removal of turbidity occurred in a higher percentage with the sodium chloride solution (91.32 %) at a dose of 20 mg/L, followed by sodium chloride (76.87%) 25 mg/L and distilled water 30 mg/L (56.60 %). Based on the above, the role played by salts in the extraction of the bioactive components of natural coagulants is highlighted, favoring the pollutant removal processes (Megersa et al., 2019).

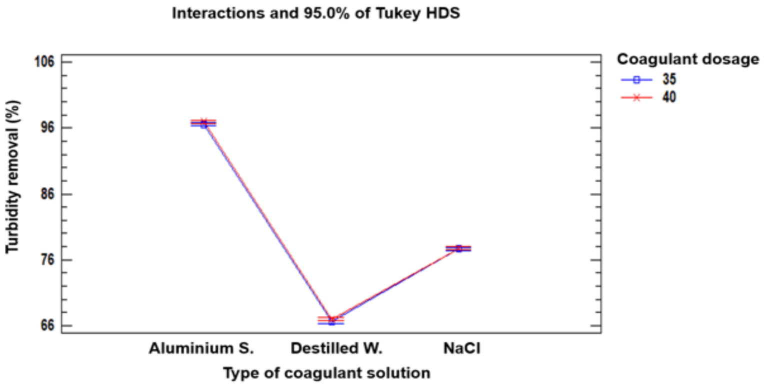
In this regard, it is possible to cite the breakdown of the protein-protein bond in Moringa oleifera coagulants, thanks to the increase in the ionic strength of the salt used, being in this case the protein content of these seeds what the authors attribute to the coagulation processes (Madrona et al., 2011).

Table 4. Turbidity removal percentages after treatment with the different coagulant solutions with tamarind seed powder in the solvents distilled water and saline solution, and Alum solution.

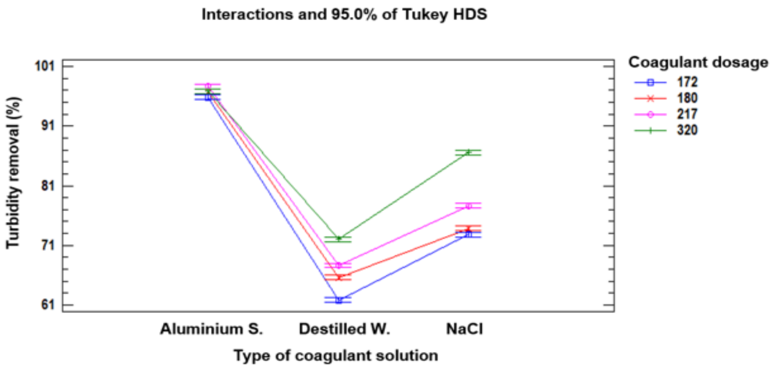
Initial turbidity of surface water (NTU)	Coagulating solution	Dosage	Turbidity removal (%)	Coagulant activity (%)
172	Solution in NaCl (1,0 N)	35 mg/L	73	71
		40 mg/L	73	71
	Solution with distilled water	35 mg/L	62	59
		40 mg/L	62	60
	Aluminium sulphate	35 mg/L	96	96
		40 mg/L	96	96
180	Solution in NaCl (1,0 N)	35 mg/L	74	72
		40 mg/L	74	73

	Solution with distilled water	35 mg/L	65	63
		40 mg/L	66	64
	Aluminium sulphate	35 mg/L	96	96
		40 mg/L	97	96
217	Solution in NaCl (1,0 N)	35 mg/L	77	76
		40 mg/L	78	76
	Solution with distilled water	35 mg/L	67	65
		40 mg/L	68	66
	Aluminium sulphate	35 mg/L	97	97
		40 mg/L	97	97
320	Solution in NaCl (1,0 N)	35 mg/L	86	85
		40 mg/L	87	86
	Solution with distilled water	35 mg/L	78	77
		40 mg/L	79	78
	Aluminium sulphate	35 mg/L	98	98
		40 mg/L	98	98

In the figure 1 shows the interactions between dosage, coagulant solutions and turbidity during coagulation.



(A)



(B)

Figure 1. The figure of interactions of the factors within the coagulation process. (A) Dosage of coagulants and initial turbidity of the samples and (B) coagulant solutions and initial turbidity of the sample. Solution in NaCl (NaCl) and Solution with distilled water (Destiled W) and aluminium sulphate (Aluminium S).

The results of the analysis of variance (ANOVA) showed that the factors coagulant solution type, coagulant dose (mg/L) and initial turbidity (NTU) have a significant effect on the percentage of turbidity removal from surface water at a confidence level of 95.0% with P-value values less than 0.05. The mean plot (Figure 1), shows that the factors of initial turbidity (NTU) and coagulant solutions in interaction are statistically significant on the percentage of turbidity removal. On the other hand, the dose of coagulant in each solution is not statistically significant in interaction with the type of coagulant solution used.

Natural coagulants are called polyelectrolytes (Yin, 2010); in the analysis of functional groups through Fourier Transform Infrared Spectroscopy (FTIR), Zainol and Nasuha Mohd Fadli (2020) demonstrated for dried seeds of T. indicates the presence of -OH functional groups, added to the carboxylic acid spectrum, together with sharp bands due to C-H and C-O-C stretching; functional groups that would be participating in the coagulation process. In contrast to the above, Dewi et al. (2021), using the same technique, demonstrated the presence of a specific peak for primary aliphatic amines and others for the functional groups of primary aliphatic alcohols and the alkene group. Attributing to the coagulant positive charges given by N-H and negative charges given by O-H. It is possible to attribute the turbidity removal rates of wastewater mainly to these functional groups, highlighting the hydroxyl group as the most active group in the polyelectrolytes innatural coagulants, in its role of destabilization within the water in the formation of floccules for precipitation (Dewi et al., 2021).

A contrast can be seen in the studies carried out with T. indica and assistants in the coagulation process (polyacrylamide), showing turbidity reductions of 93.62% for coagulant doses of 15pppm and 0.5% polyacrylamide, with an initial turbidity of 26.5 NTU. Within the comparison tests with inorganic coagulant such as Poly Aluminium Chloride (PAC) showing average turbidity reductions of 96.20% for initial turbidity conditions of 26.5 NTU and using 0.5% polyacrylamide; results that could be demonstrating the action of the natural coagulant and the benefits of its application in the reduction of surface water turbidity (Mostafizur Rahman et al., 2015). In the trials conducted by Carrasquero et al., 2019, the water purification process is based on the use of coagulants from T. indica seeds with the preparation of coagulant solutions with non-fat and defatted seeds. It is shown that at a dose of 10mg/L in 200 NTU water, the percentage of removal reaches 82.3% for solutions with defatted seeds; on the other hand, for the solution without defatting, percentages higher than 96.7% are obtained at a turbidity of 200 NTU and a dose of 50mg/L. From the above tests, it can be seen that there are significant differences in the removal of the different turbidities, as well as between the coagulating solutions, with the one that includes seeds without defatting being the most effective in the treatment. Removal percentages that the authors can attribute to the presence of glutamic and aspartic acids, which are made up of groups with a formal negative charge that participate in the destabilization and coagulation of colloidal particles.

In the treatment of industrial wastewater, turbidity removal percentages of 86.15% at a dose of 48 mg/L are cited for coagulant solutions of T. indica in dairy industry water with an initial turbidity of 195 NTU. Likewise, for the rubber processing industry, 65% removal at a dose of 1250 mg/L with an initial value of 465 NTU is evidenced (Lakshmi et al., 2017).

CONCLUSIONS

The study trials with different initial turbidity values (172 NTU, 180 NTU, 217 NTU, 320 NTU) show higher turbidity removal percentages in solutions prepared with aluminium sulphate as control coagulant reaching 98%, in contrast for coagulant solutions of T. indica coagulant solutions prepared with NaCl 1.0 show between 86% and 87%, with significant differences between the coagulant solutions evaluated, while for doses of 35mg/L and 40mg/L there are no differences between the amount of coagulant used. indica can be used as a coagulant in the process of surface water clarification, considering its environmental importance as it is a natural product that allows the use of agro-industrial waste and minimizes the impact of the use of chemical products that are harmful to the environment, becoming a green technology to replace the use of resources in the region.

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AUTHORSHIP CONTRIBUTIONS

All authors have jointly and equally contributed to the argumentation and writing of the manuscript.

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7. CONFLICT OF INTEREST

None.

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