CIÊNCIA e NATURA
ISSN 2179-460X
OPEN ACCESS
Ci. e Nat., Santa Maria, v. 47, e90969, 2025 • https://doi.org/10.5902/2179460X90969
Submitted: 02/24/2024 • Approved: 05/29/2025 • Published: 06/17/2025

Environment

Use of agricultural waste: pitaya cladode in sustainable treatment of water for human consumption - part 1

Aproveitamento de resíduos agrícolas: cladódio de pitaia no tratamento sustentável de água para consumo humano - parte 1

Emili Borges Carlos[I], **Suzana Frighetto Ferrarini**[I], **Airton Luiz Bortoluzzi**[II], **Márcia dos Santos Ramos Berreta**[I], **Daniela Mueller de Lara**[I]

[I] Universidade Estadual do Rio Grande do Sul, Porto Alegre, RS, Brazil
[II] Instituto Federal Catarinense, Blumenau, RS, Brazil

ABSTRACT

This study investigates the innovative use of dragon fruit cladode (*Selenicereus undatus* (Haw.) D.R. Hunt) as a natural coagulant for drinking water treatment, offering a sustainable alternative to traditional chemical coagulants. The cladode, an abundant agricultural byproduct, was directly applied as a powder without extraction steps, highlighting the originality, simplicity, and feasibility of the method. Tests conducted under different pH conditions and rapid mixing times demonstrated that at pH 3, the cladode achieved performance equivalent to aluminum sulfate, with turbidity removals exceeding 90% after 12 minutes of agitation. While the removal of apparent color at natural pH showed some limitations, extending the agitation time significantly improved the coagulant's efficiency. This study underscores the potential of dragon fruit cladode for decentralized water treatment, particularly in rural communities or regions with limited access to conventional coagulants, promoting the reuse of regional agricultural waste as an innovative, sustainable, and accessible solution to improve water quality in areas with constrained infrastructure.

Keywords: Biocoagulants; Agricultural waste management; Water quality

RESUMO

Este estudo investiga o uso inovador do cladódio de pitaia (*Selenicereus undatus* (Haw.) D.R. Hunt) como coagulante natural no tratamento de água para consumo humano, propondo uma alternativa sustentável aos coagulantes químicos tradicionais. O cladódio, um subproduto agrícola abundante gerado durante a poda anual, foi utilizado diretamente em pó, sem etapas de extração, destacando a originalidade, simplicidade e viabilidade do método. Testes realizados em diferentes condições de pH e tempos de agitação rápida mostraram que, em pH 3, o cladódio apresentou desempenho equivalente ao sulfato de alumínio, alcançando remoções de turbidez superiores a 90 % com 12 minutos de agitação. Embora em pH natural a remoção de cor aparente tenha apresentado limitações, o aumento do tempo de agitação melhorou significativamente a eficácia do coagulante. Este estudo reforça o potencial do cladódio de pitaia para o tratamento descentralizado de água, especialmente em comunidades rurais ou regiões com acesso restrito a coagulantes convencionais, promovendo o reaproveitamento de resíduos agrícolas regionais como uma solução inovadora, sustentável e acessível para melhorar a qualidade da água em áreas de infraestrutura limitada.

Palavras-chave: Biocoagulantes; Gestão de resíduos agrícolas; Qualidade da água

1 INTRODUCTION

With the increase in demand for drinking water in quantity and quality, concern is also growing about the environmental and public health impacts resulting from the use of traditional chemical coagulants, widely used in water treatment (Lima Júnior, 2018). These coagulants, such as aluminum salts, are effective but generate residues that can affect the quality of the sludge and pose risks to human health, such as the development of neurodegenerative diseases (Cruz & Silva Neto, 2020). Thus, the search for more sustainable, efficient, and economically viable alternatives becomes essential, driving interest in biocoagulants derived from plant sources, which offer less environmental impact and can be applied in contexts where conventional coagulants are inaccessible.

Coagulation is a significant step in water treatment for human consumption and, together with flocculation, reduces turbidity, color, and organic matter, in addition to lowering metal ion levels (Tebbut, 1982 apud Hendrawati, 2016). Although the terms coagulation and flocculation are often used synonymously, they represent distinct processes. Coagulation involves the addition of a coagulating agent to neutralize the forces that keep particles suspended, a process that occurs during rapid agitation. Then, flocculation, conducted during slow agitation, promotes the agglomeration of particles, forming larger and heavier flakes that facilitate the sedimentation of impurities (Ritcher & Azevedo Netto, 2003).

Currently, inorganic coagulants, such as iron and aluminum salts or synthetic polymers, are widely used in Water Treatment Plants (WTPs). Despite the proven efficacy of these agents, the use of aluminum-based coagulants raises concerns due to possible correlations between residual aluminum in treated water and neurodegenerative diseases, such as Alzheimer's (Cruz & Silva Neto, 2020).

Natural coagulants derived from plants, known as biocoagulants, have immense potential as alternatives to commercial coagulants (Hendrawati, 2016). They stand out for characteristics such as solubility in water, wide range of pH, non-toxicity, non-corrosiveness, availability on a large scale, and production of biodegradable sludge in smaller volumes compared to those generated by chemical coagulants (Lima Júnior, 2018). Furthermore, this sludge can be composted and used as organic fertilizer, contributing to sustainable agricultural practices (Lima et al., 2020).

Moringa (*Moringa oleifera Lam*.) is a plant widely used in water treatment whose seeds are efficient in removing turbidity and organic matter (Hendrawati, 2016). In addition to moringa, cacti such as *Opuntia spp*. have demonstrated efficiency in removing suspended solids (Miller et al., 2008).

Although the literature on pitaya cladode (*Hylocereus spp*.) as a natural coagulant is scarce, some studies point to its potential. Shafad et al. (2013) identified that the pitaya cladode presents turbidity removal comparable to aluminum, with a lower dosage, better results at neutral pH, and a reduced sedimentation time, ideal for fast processes. Rayudu et al. (2022) also verified efficiency in turbidity removal, highlighting that combining cladode with aluminum reduced the amount of the latter required, increasing efficiency, and reducing costs and environmental impacts. Both studies used an additional extraction process with deionized water after the conversion of the cladode into powder.

Although the studies on pitaya cladode mainly focused on the treatment of industrial effluents, with promising results in removing solids and reducing pollutants

(Som et al., 2021; Som & Wahab, 2018; Idris et al., 2013), the cladode has ideal characteristics for use as a natural coagulant in complex effluents due to its positive charge and biodegradability, which reduce environmental impact and generate non-toxic sludge (Som et al., 2021; Som & Wahab, 2018).

The literature on pitaya focuses mainly on the use of the fruit, especially in the food industry and in cosmetic applications, due to its nutritional and bioactive profile. Rich in compounds such as betalains, polyphenols, vitamins B and C, and minerals such as potassium, iron, and calcium, the fruit has antioxidant and anti-inflammatory properties and is used in juices, jams, wines, and desserts. Furthermore, its peel, rich in pectin, is used as a thickening agent in biodegradable packaging and in the production of cellulose nanomaterials, which can be used as adsorbents for toxic metals and antimicrobial materials (Da Costa & Carvalho, 2023; Shah et al., 2023; Anh et al., 2021; Kakade et al., 2022; Dos Santos et al., 2022).

Cladode pruning, a widespread practice in commercial crops to improve fruit productivity, generates large volumes of plant residue without a defined application (Pushpakumara et al., 2005). The use of cladodes as a natural coagulant represents a sustainable alternative for this agricultural byproduct (Idris et al., 2013), enabling its use in decentralized water treatment contexts, especially in rural communities or those far from large urban centers, where access to conventional coagulants may be restricted.

In this sense, this study aims to evaluate the potential of pitaya (*Selenicereus undatus* (Haw.) D.R. Hunt) cladode as a sustainable biocoagulant in the treatment of water for human consumption, comparing its effectiveness with moringa seed and the chemical coagulant aluminum sulfate. Its originality lies in the direct application of the powdered cladode without coagulant extraction, providing a simplified, sustainable, and potentially applicable method in places with limited infrastructure.

As an initial part of a broader investigation, this article evaluates the ideal pH conditions and rapid agitation time to maximize coagulant efficiency, analyzing essential water quality parameters, such as turbidity and color, in compliance with Brazilian regulatory standards. The second stage of this research, presented in a subsequent article, expands the analysis by exploring the influence of different concentrations of coagulants on the same parameters, with the inclusion of Dissolved Organic Carbon (DOC), deepening the understanding of the viability and practical application of the biocoagulant. In addition to investigating these ideal operating conditions, this study serves as a basis for future tests that evaluate additional aspects of water quality, consolidating the pitaya cladode as an environmentally safe and economically viable alternative. Therefore, it promotes decentralized treatment solutions, especially in areas with limited access to conventional coagulants.

2 METHODOLOGY

2.1 Objective and Comparative Strategy

This study was designed to evaluate and compare the efficiency of pitaya cladode, moringa, and aluminum sulfate as coagulants for drinking water treatment. In addition to verifying the ideal acidic and natural pH conditions for the pitaya cladode, this investigation aims to assess the viability and sustainability of this plant coagulant for direct use (without an extraction step) and its application in areas with limited access to chemical coagulants.

2.1.1 Description of the Study Area

Itapeva Lagoon was selected as the study area due to its economic, cultural, environmental, and political relevance for the region. This lagoon, belonging to the Tramandaí River Basin, supplies the city of Torres, in Rio Grande do Sul, through the distribution system of the Rio Grande do Sul Sanitation Company (CORSAN) (Castro, 2019). Water samples were collected directly at CORSAN's Water Treatment Plant (WTP), located on the north bank of Itapeva Lagoon, before any treatment. The collection followed the guidelines of the Brazilian National Guide for Collection and Preservation of Samples of the Brazilian National Water and Basic Sanitation Agency (Ana, 2023), ensuring adequate preservation for analysis.

2.1.2 Preparation of Coagulants

2.1.2.1 Pitaya Cladode (Selenicereus undatus (Haw.) D.R. Hunt)

The cladodes were collected in the garden of the Federal Institute of Santa Catarina (IFC), Santa Rosa do Sul/SC campus. After removing the spines, they were washed and cut transversely into slices 0.5 to 1 cm thick (Idris et al., 2013). The slices were dried in an oven at 65 °C until constant weight (Malavolta et al., 1997), crushed in a knife mill, and sieved to use the particle size fractions smaller than 600 μm.

2.1.2.2 Moringa Seeds (Moringa oleifera Lam.)

The seeds were macerated in a mortar and dried in an oven at 40 °C until constant weight (Hendrawati et al., 2016), without additional sieving due to oiliness.

2.1.2.2 Aluminum Sulfate

A concentrated solution of 5000 mg/L^{-1} of aluminum sulfate P.A was prepared for use in the tests.

2.1.2.3 Coagulation Assays

The coagulation tests were conducted at the IFC Soil Laboratory using JarTest equipment with a capacity of 1 L. The operating conditions were rapid stirring at 120 rpm for 1 minute, followed by slow stirring at 30 rpm for 20 minutes, and resting for 1 hour for sedimentation (Idris et al., 2013).

2.1.3 Tests Performed

Two triplicate tests were performed to identify the best conditions for coagulants to act in water treatment:

2.1.3.1 Test I - Influence of pH on the Water Clarification Process

The pH of the water was varied between 2 and 11, with a fixed rapid stirring time of 1 minute, to identify the pH with the best performance for each coagulant.

2.1.3.2 Test II - Influence of Rapid Agitation Time on the Water Clarification Process

The pH identified in Test I was used for each coagulant (pH 3 for pitaya cladode, pH 6 for aluminum sulfate, and natural pH for moringa), varying the rapid agitation time by 1, 4, 8, and 12 minutes, according to previous experiments and literature (Yu et al., 2011; Di Bernardo et al., 2005; Kan et al., 2002). Table 1 summarizes the varied and fixed parameters for each test.

Table 1 – Varied and fixed parameters in Tests I and II

	Water pH	**Rapid stirring time (min) at speed 120 rpm**	**Coagulant concentration ($mg.L^{-1}$)**
Test I - Influence of pH on the Water Clarification Process	Variable evaluated: range 2 to 11	Fixed parameter: 1	Fixed parameter: Pitaya: 100 Moringa: 100 Aluminum sulfate: 25
Test II - Influence of Rapid Agitation Time on the Water Clarification Process	Fixed parameter: Pitaya pH 3 and natural pH; Moringa natural pH. Aluminum sulfate pH 6	Variable evaluated: 1, 4, 8 e 12	Fixed parameter: Pitaya: 100 Moringa: 100 Aluminum sulfate: 25

Source: Authors (2025)

The concentration of aluminum sulfate was defined based on the levels generally used by the local sanitation utility, while the concentrations for the vegetable coagulants were based on previous studies (Hendrawati et al., 2016; Idris et al., 2013). In Test II, the performance of pitaya cladode at pH 3 and natural pH was compared to aluminum sulfate and moringa to evaluate the effect of rapid agitation time on the removal of turbidity and apparent color.

2.1.4 Monitored Potability Parameters

The efficiency of the coagulants was evaluated based on the parameters of turbidity, pH, and apparent color (wavelength of 460 nm) (Apha, 2023) according to the potability criteria defined by Ordinance GM/MS 888/21.

2.1.4.1 Statistical Analysis

Statistical analysis was conducted using the SISVAR software developed by the Department of Statistics of the Federal University of Lavras (UFLA). In a completely randomized design, the Tukey test was applied to compare means with a significance level of 5%.

3 RESULTS AND DISCUSSIONS

The raw water used in this study was characterized to measure essential potability parameters. The mean initial values are presented in Table 2 and were measured before each test, aiming to evaluate the efficiency of the proposed coagulation and flocculation process.

Table 2 shows that water's turbidity and apparent color values in Itapeva Lagoon exceed the limits established by Ordinance GM/MS 888/2021, highlighting the need for treatment before distribution for human consumption. Additional monitoring data (such as turbidity, BOD, and iron) provided by the Sanitation Company throughout 2021 indicate that the water exceeds the limits for Class 2 of CONAMA Resolution 357/2005, falling into Class 3 for some specific parameters. This classification reinforces the need for advanced treatment to guarantee the potability and safety of public supply (Brasil, 2005).

Table 2 – Initial physical-chemical parameters of the water from Itapeva Lagoon

Test	Turbidity (uT)	Apparent color (uH)	pH
I - Influence of pH on the Water Clarification Process	17.43	163.14	7.44
II- Influence of Rapid Agitation Time on the Water Clarification Process	21.83	161.37	7.29
Mean value	19.63	162.25	7.36
Standard Deviation	3.11	1.25	0.1
MPV[a] - Ordinance GM/MS 888/21	5	15	6 to 9

[a]MPV - Maximum Permitted Value. Source: Authors (2025)

3.1 Test I – Influence of pH on the Water Clarification Process

The pH is a critical parameter in coagulation and flocculation as it directly affects the performance of natural and chemical coagulants (Som et al., 2021). Table 3 presents the results for turbidity removal at different pH, while Table 4 presents the apparent color values, indicating how performance varies according to pH for each coagulant.

At extreme pH values (pH 2), the water showed good clarification even without using coagulants (blank analysis). This phenomenon may be related to the variable load of inorganic and organic materials that cause turbidity and color, a characteristic influenced by the soil composition in the region (Stumm & Morgan, 1981 apud Fontes et al., 2001). In this sense, the Zero Charge Point (ZPC) of the colloidal particles present minimized the electrostatic repulsion and favored their spontaneous flocculation, resulting in water clarification (Fontes et al., 2001). The ZPC varies according to the mineral composition of the soil, ranging between pH 2 and 4 for some Si and Mn oxides and between pH 8 and 10 for certain Fe and Al oxides, which reinforces this observation (Fontes et al., 2001).

Table 3 – Influence of pH (T2) on turbidity removal by different coagulants (T1)

pH	Blank	Aluminum sulfate (25 mg L^{-1})	Pitaya cladode (100 mg L^{-1})	Moringa (100 mg L^{-1})
		Turbidity removal (%)		
2	94.75 b A	95.97 d A	94.63 e A	98.60 a A
3	15.55 a A	89.40 d B	91.55 e B	94.55 a B
4	12.55 a A	93.61 d B	14.51 ab A	88.98 a B
5	12.90 a A	96.05 d B	12.22 ab A	86.70 a B
6	12.20 a A	96.08 d B	13.75 ab A	89.79 a B
7	12.02 a A	67.66 c B	17.96 abc A	89.17 a C
8	10.78 a A	42.28 b B	22.35 bcd A	90.09 a C
9	11.84 a A	75.90 cd C	35.47cd B	91.35 a C
10	11.31 a A	88.03 cd C	40.51 d B	91.89 a C
11	8.31 a A	9.68 a A	36.87 cd B	93.06 a C
CV%	14.1			
		Pr>Fc		
T1 within T2	0.001			
T2 within T1	0.001			

Where: lowercase letters indicate statistically significant differences between rows; uppercase letters indicate statistically significant differences between columns. CV - Coefficient of variation of repetitions; Pr>Fc - Significance of the F value for the T2 evaluations at each T1 level and of T1 at each T2 level (Tukey test). Source: Authors (2025)

The chemical coagulant aluminum sulfate showed its highest efficiency in removing turbidity in the pH range between 3 and 6 (Table 3), confirming its effectiveness within the range commonly used in WTPs. The pitaya cladode, in turn, demonstrated maximum efficiency at pH 3, with 91.55% turbidity removal, and a second performance at pH 10, reaching 40.51% removal. This behavior is consistent with Idris et al., (2013), who observed equivalent results with pitaya cladode in industrial effluents from rubber processing.

Previous studies have demonstrated the potential of pitaya cladode as a natural coagulant under different pH and concentration conditions. Shafad et al., (2013) reported that powdered pitaya cladode showed considerable efficiency in removing turbidity in neutral pH water, especially at low concentrations, reaching up to 85% removal at initial turbidity of 400 NTU with less than 20 mg/L^{-1}. Rayudu et al., (2022) complemented this finding by reporting turbidity removals close to 84% in waters with an initial turbidity of

55 NTU, using a concentration of 250 mg/L^{-1}. In the present study, however, the maximum efficiency of pitaya cladode was obtained at acidic pH (pH 3), achieving 91.55% turbidity removal at a moderate concentration (100 mg/L^{-1}), a performance comparable to that of aluminum sulfate at the ideal conditions of pH 3 to 6.

Furthermore, it is noteworthy that this study uses pitaya cladode powder directly, without the coagulant extraction step, differing from the methodologies used in previous studies. This approach simplifies the process, making it more accessible for applications in locations with limited infrastructure. The results, therefore, reinforce the potential of pitaya cladode as a sustainable and easily applicable alternative for water treatment, especially in rural communities or regions with restricted access to conventional coagulants.

According to Freitas et al., (2015), the adsorption of cations in natural adsorbents is favored at pH above the charge neutrality point (Zeta Potential), while the adsorption of anions occurs at pH below this point. In studies by Idris et al., (2013) with the pitaya cladode (H. undatus), the charge neutrality point in distilled water remained stable between pH 4 and 8, a range corresponding to the lowest turbidity removals observed in this study. The higher removal of turbidity (Table 3) and apparent color (Table 4) at pH 3 indicates the predominance of negatively charged particles in the raw water of Itapeva Lagoon, a characteristic confirmed by Libânio (2010), who reports that the colloidal particles in the water are mainly negative.

Moringa seed demonstrated consistent performance across the pH range, achieving turbidity removals higher than 87% at all pH values assessed and showing similar efficacy to aluminum sulfate at pHs 7, 8, and 11. Studies such as those by Ndabigengesere and Narasiah (1998) also confirm this versatility of moringa in varying pH conditions. It is worth noting that the use of moringa (Moringa oleifera) in water treatment is already widely accepted, with consistent evidence of its efficiency in removing turbidity at different pHs values (Franco et al., 2017; Hendrawati et al., 2016), and it was used in this study for comparative purposes.

Table 4 – Influence of pH (T2) on removing the apparent color by different coagulants (T1)

pH	Blank	Aluminum sulfate (25 mg L^{-1})	Pitaya cladode (100 mg L^{-1})	Moringa (100 mg L^{-1})
		Apparent color values (uH)		
2	28.33 a A	145.74 cde B	17.59 a A	46.48 a A
3	150.19 b B	33.89 ab A	23.52 ab A	17.59 a A
4	148.70 b B	27.03 ab A	154.99 c B	33.14 a A
5	147.22 b B	22.77 ab A	159.07 c B	35.37 a A
6	152.77 b B	18.52 a A	122.03 bc B	37.22 a A
7	159.07 b B	65.37 abcd A	154.25 c B	33.14 a A
8	153.51 b B	120.92 bcde B	147.59 c B	27.22 a A
9	153.15 b B	51.67 abc A	133.52 c B	27.22 a A
10	154.63 b B	19.44 ab A	130.92 c B	22.04 a A
11	155.00 b B	166.11 de B	126.11 c B	25.00 a A
CV%	38.07			
		Pr>Fc		
T1 within T2	0.001			
T2 within T1	0.001			

Where: lowercase letters indicate statistically significant differences between rows; uppercase letters indicate statistically significant differences between columns. CV - Coefficient of variation of repetitions; Pr>Fc - Significance of the F value for the T2 evaluations at each T1 level and of T1 at each T2 level (Tukey test) Source: Authors (2025)

For the apparent color parameter (Table 4), aluminum sulfate performed better at pH 6, in line with the recommendations of Viessman and Hammer (2004), who identify the range between pH 5.5 and 8 as ideal for using this coagulant. On the other hand, the pitaya cladode had its maximum effectiveness at pH 3, a behavior also reported in other cacti, such as the prickly pear (Antilon et al., 2012).

Moringa showed better performance for the apparent color parameter at pH 8 and 11, remaining comparable to aluminum sulfate at the other pH values. However, none of the coagulants assessed managed to reach the 15 uH limit established by Ordinance GM/MS 888/21 for apparent color.

For Test II, the best-performing pHs for each coagulant were selected: natural pH (~7) for moringa, pH 6 for aluminum sulfate, and pH 3 for pitaya cladode, with the inclusion of the natural pH for the latter, allowing a more robust comparative analysis.

3.2 Test II – Influence of Rapid Agitation Time on the Water Clarification Process

The rapid agitation step allows uniform mixing between the coagulant and the sample, facilitating the formation of flocs (Libânio, 2010). The speed gradients favor encounters between particles, enabling the formation of larger and denser flakes (Di Bernardo et al., 2017). In Test II, the rapid agitation time was varied between 1, 4, 8, and 12 minutes to evaluate the performance of the coagulants.

For the turbidity (Table 5A) and apparent color (Table 5B) parameters, aluminum sulfate and pitaya cladode at pH 3 did not present statistically significant differences over the tested times, reaching removals above 90% at all times. However, for the pitaya cladode at pH 3, agitation times of 8 and 12 minutes provided slightly higher removals, reaching 97.40% and 98.2% turbidity, respectively. These values indicate that the pitaya cladode may exhibit even higher efficiency with prolonged contact time, suggesting a potential need for adjustment in agitation time to optimize its performance.

The pitaya cladode and moringa at natural pH demonstrated variation in efficiency according to the rapid agitation time. Moringa showed good performance in short times (1 and 4 minutes), with turbidity removal of 87.76% in 1 minute, which is close to enough to meet the turbidity limit of 5 uT established by Ordinance GM/MS 888/2021, although still lower than the performance of aluminum sulfate. This performance reflects the effectiveness of moringa at reduced contact times, a result also observed by Cardoso et al., (2008) at neutral pH. The pitaya cladode at natural pH required longer agitation (8 and 12 minutes) to reach an effective removal level, with removal percentages of 74.62% and 88.27%, respectively.

Table 5 – Effect of rapid agitation time (T2) on the removal of turbidity (5A) and apparent color (5B) after use of coagulants (T1)

A - Turbidity removal percentage				
Rapid agitation time (min)	**Aluminum sulfate (25 mg L^{-1}) - pH 6**	**Pitaya cladode (100 mg L^{-1}) - pH 3**	**Pitaya cladode (100 mg L^{-1}) - natural pH**	**Moringa (100 mg L^{-1}) - natural pH**
Blank	0.00 a A	0.00 a A	0.00 a A	0.00 a A
1	97.50 b B	89.74 b B	35.86 b A	87.76 c B
4	99.34 b B	94.82 b B	37.70 b A	81.60 c B
8	99.10 b B	97.40 b B	74.62 c B	73.77 bc B
12	98.85 b B	98.2 b B	88.27 c B	50.02 b A
CV%	18.65			
		Pr[d]>Fc[e]		
T1 within T2	0.001			
T2 within T1	0.001			

B - Apparent color (uH)				
Rapid agitation time (min)	**Aluminum sulfate (25 mg L-1) - pH 6**	**Pitaya cladode (100 mg L^{-1}) - pH 3**	**Pitaya cladode (100 mg L^{-1}) - natural pH**	**Moringa (100 mg L^{-1}) - natural pH**
Blank	161.37 b A	161.37 b A	161.37 c A	161.37 d A
1	16.19 a A	37.30 a A	164.70 c B	39.15 a A
4	12.11 a A	23.22 a A	157.29 c C	55.45 ab B
8	10.26 a A	17.67 a A	82.48 b B	69.89 b B
12	12.11 a A	14.33 a A	49.52 a B	105.81 c C
CV%	15.88			
		Pr>Fc		
T1 within T2	0.001			
T2 within T1	0.001			

Where: lowercase letters indicate statistically significant differences between rows; uppercase letters indicate statistically significant differences between columns. CV - Coefficient of variation of repetitions; Pr>Fc - Significance of the F value for the T2 evaluations at each T1 level and of T1 at each T2 level (Tukey test). Source: Authors (2025)

In comparison, aluminum sulfate at pH 6 achieved a removal percentage of 97.50% in 1 minute and maintained values of 97.50% or higher at all times assessed, meeting the turbidity limit under all conditions. Regarding the apparent color parameter, aluminum sulfate met the limit of 15 uH in agitation times starting from 4 minutes, while the pitaya cladode at pH 3 met this limit only with 12 minutes of rapid agitation.

These results highlight the need to adjust the agitation time for each coagulant and reinforce the consistency of moringa as an efficient alternative for turbidity removal, especially at shorter contact times.

Statistical analysis of the results, applying the Tukey test, revealed that, in the removal of turbidity, the pitaya cladode at pH 3 presented statistically equivalent performance to aluminum sulfate at agitation times of 8 and 12 minutes, with removal values higher than 97%. However, for the apparent color parameter, pitaya cladode met the regulated limit only after 12 minutes of rapid agitation, differing significantly from moringa and aluminum sulfate ($p < 0,05$). Moringa was effective in shorter times, while aluminum sulfate was efficient throughout the range of times studied. These data suggest that agitation time is a critical variable for optimizing pitaya cladode performance, especially under decentralized treatment conditions.

The results reinforce the potential of pitaya cladode as a promising biocoagulant, especially at acidic pH, presenting performance comparable to aluminum sulfate. These findings support the continuation of the research, which will evaluate how different concentrations influence additional parameters, such as DOC, in search of practical and sustainable solutions for water treatment.

4 CONCLUSIONS

This article presents significant contributions by highlighting the potential of pitaya cladode as a plant coagulant in the treatment of water for human consumption, meeting, under different conditions, the potability parameters of Ordinance GM/MS 888/2021. The use of agricultural waste as raw material promotes the economic development of rural producers and represents an advance in the replacement of chemical coagulants, reducing environmental impacts related to waste in treated water and in the sludge generated.

At pH 3, pitaya cladode demonstrated statistically equivalent performance to aluminum sulfate in turbidity removal, proving its effectiveness in acidic conditions.

However, with just 12 minutes of rapid agitation, it was possible to meet the potability limit for apparent color established by legislation, suggesting that its use may be more suitable for effluents or naturally acidic waters, where pH adjustments are already part of the process.

Under natural pH conditions, pitaya and moringa cladodes showed efficiency in turbidity removal. However, both presented limitations in meeting the apparent color parameter, as required by Brazilian legislation. Adapting operational variables, such as extended agitation times, demonstrated the potential to optimize pitaya cladode performance, especially in decentralized applications.

Unlike most studies that explore the use of the fruit, this study stands out for its innovation in investigating the pitaya cladode applied directly in powder form without prior extraction of the coagulant. This approach simplifies the process, reduces costs, and increases the viability of application in areas with limited infrastructure. The absence of publications documenting this application for drinking water reinforces this research's originality and practical relevance.

The results indicate that the direct use of pitaya cladode in decentralized processes may represent an environmentally safe and economically accessible solution for water treatment in rural communities or regions with restricted access to conventional coagulants. The study highlights the biocoagulant sustainable and regional potential, promoting the use of local resources and contributing to the development of safer and more economically viable alternatives.

Furthermore, this article lays the foundation for future research, which should explore the influence of coagulant concentrations on additional parameters, such as DOC, and investigate the performance of pitaya cladode in different types of water, especially those with lower organic load. It is also recommended to evaluate strategies that economically enable large-scale pH adjustments, expanding the applicability of this biocoagulant. These perspectives strengthen the practical impact of research and open paths to develop affordable and sustainable technologies aimed at decentralized water treatment systems.

REFERENCES

Agência Nacional de Águas e Saneamento Básico, & Companhia Ambiental do Estado de São Paulo (2023). *Guia nacional de coleta e preservação de amostras: Água, sedimento, comunidades aquáticas e efluentes líquidos* (2 ed). ANA/CETESB.

American Public Health Association, American Water Works Association, & Water Environment Federation (2023). *Standard methods for the examination of water and wastewater* (24 ed.). American Public Health Association.

Anh, T. P. T, Nguyen, T. V, Hoang, P. T, Thi, P. V, Kim, T. N, Van, Q. N, Van, C. N, & Hai, Y. D. (2021) Dragon fruit foliage: An agricultural cellulosic source to extract cellulose nanomaterials. *Molecules*, 26(24), 7701. doi: 10.3390/molecules26247701

Antilon, J. A., Camareno, M. V., & Bustos, N. Q. (2012). Evaluación de la tuna (*Opuntia cochenillifera*) para la remoción del color en agua potable. *Tecnología en Marcha*, 25(4), 55–62. doi: 10.18845/tm.v25i4.619

Brasil. Conselho Nacional do Meio Ambiente – CONAMA (2005). Resolução nº 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes. *Diário Oficial da União*, seção 1.

Brasil. Ministério da Saúde (2021). Portaria nº 888, de 4 de maio de 2021. Estabelece os procedimentos e os critérios para o controle e a vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. *Diário Oficial da União*, seção 1.

Cardoso, K. C., Bergamesco, R., Cossich, E. S., & Moraes, C. K. (2008). Otimização dos tempos de mistura e decantação no processo de coagulação/floculação da água bruta por meio da *Moringa oleifera* Lam. *Acta Scientiarum*. *Technology*, 26(2), 2178–2189. doi: 10.4025/actascitechnol.v30i2.5493

Castro, D. (2019). *Ciclo das águas na bacia do Tramandaí* (1. ed.). Via Sapiens. doi: https://taramandahy.org.br/project/ciclo-das-aguas-na-bacia-do-rio-tramandai/

Cruz e Silva Neto, G., Morais, S. N., Costa, F. H. A., Santos, L. A. S., Rodrigues, J. C., Silva, T. A., Alves, W. S., & Ykeda, D. S. (2020). O nível de concentração de alumínio na água como fator de risco para o desenvolvimento da doença de Alzheimer. *Brazilian Journal of Health Review*, 3(5), 15324–15339. doi: 10.34119/bjhrv3n5-311

Da Costa, L. M., & Carvalho, R. F. (2023). *Produção de embalagens biodegradáveis com a casca da pitaya e engaços de dendê* (Monografia de Bacharelado). Universidade Federal Rural da Amazônia. Available in: https://bdta.ufra.edu.br/jspui/handle/123456789/2828

Di Bernardo, L., Botari, A., & Paz, L. S. (2005). Uso de modelação matemática para projeto de câmaras mecanizadas de floculação em série em estações de tratamento de água. *Engenharia Sanitária e Ambiental*, 10(1). doi: 10.1590/S1413-41522005000100010

Di Bernardo, L., Dantas, D. B. A., & Voltan, P. E. N. (2017). *Métodos e técnicas de tratamento de água* (3. ed.). LDiBe.

Dos Santos, D. N., Pio, L. A. S., & Faleiro, F. G. (2022). *Pitaya: Uma alternativa frutífera*. ProImpress.

Fontes, M. P. F., Camargo, O. A., & Sposito, G. (2001). Eletroquímica das partículas e sua relação com a mineralogia de solos altamente intemperizados. *Scientia Agricola*, 58(3), 627–646. doi: 10.1590/S0103-90162001000300029

Franco, C. S., Batista, M. D. A., Oliveira, L. F. C., Kohn, G. P., & Fia, R. (2017). Coagulação com semente de *Moringa oleifera* preparada por diferentes métodos em águas com turbidez de 20 a 100 UNT. *Engenharia Sanitária e Ambiental*, 22(4), 781–788. doi: 10.1590/S1413-41522017145729

Freitas, F. B. A., Camara, M. Y. F., & Martins, D. F. F. (2015). Determinação do PCZ de adsorventes naturais utilizados na remoção de contaminantes em soluções aquosas. *Blucher Chemistry Proceedings*, 3(1). doi: 10.5151/chenpro-5erq-am1

Hendrawati, Y., Yuliaustri, I. R., Nurhasni, Rohaeti, E., Effendi, H., & Darusman, L. K. (2016). The use of *Moringa oleifera* seed powder as coagulant to improve the quality of wastewater and ground water. *Earth and Environmental Science*, 31, 012033. doi: 10.1088/1755-1315/31/1/012033

Idris, J., Som, A. M., Musa, M., Hamid, K. H. K., Husen, R., & Rodhi, M. N. M. (2013). Dragon fruit foliage plant-based coagulant for treatment of concentrated latex effluent: Comparison of treatment with ferric sulfate. *Journal of Chemistry*, 2013, 230860. doi: 10.1155/2013/230860

Kakade, V., Morade, A., & Kadam, D. (2022). Dragon Fruit (*Hylocereus undatus*). In S. N. Ghosh & R. R. Sharma (Eds.), *Tropical Fruit Crops: Theory to Practical* (pp. 241–257). Editora Narendra.

Kan, C., Huang, C., & Pan, J. R. (2002). Time requirement for rapid-mixing in coagulation. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 203, 1–9. doi: https://doi.org/10.1016/S0927-7757(01)01095-0

Libânio, M. (2010). *Fundamentos de qualidade e tratamento de água* (3. ed.). Átomo.

Lima Júnior, R. N. (2018). *Uso de quitosana e carboximetilquitosana como biocoagulantes para tratamento de águas de elevada turbidez* (Dissertação de mestrado). Universidade Estadual do Ceará. Available in: https://siduece.uece.br/siduece/trabalhoAcademicoPublico.jsf?id=88083

Lima, P. R., Almeida, I. V., & Vicentini, V. E. P. (2020). Os diferentes tipos de coagulantes naturais para o tratamento de água: Uma revisão. *Evidência*, 20(1), 9–22. doi: https://doi.org/10.18593/eba.24704

Malavolta, E., Vitti, G. C., & Oliveira, S. A. (1997). *Avaliação do estado nutricional de plantas: Princípios e aplicações* (2. ed.). Potafos.

Miller, S. M., Fugate, E. J., Craver, V. O., Smith, J. A., & Zimmerman, J. B. (2008). Toward understanding the efficacy and mechanism of Opuntia spp. as a natural coagulant for potential application in water treatment. *Environmental Science & Technology*, 42(12), 4274–4279. doi: 10.1021/es7025054

Ndabigengesere, A., & Narasiah, K. S. (1998). Quality of water treated by coagulation using *Moringa oleifera* seeds. *Water Research*, 32(3), 781–791. doi: 10.1016/S0043-1354(97)00295-9

Pushpakumara, D. K. N. G., Gunasena, H. P. M., & Kariyawasam, M. (2005). Flowering and fruiting phenology, pollination vectors and breeding system of dragon fruit (Hylocereus spp.). *Journal of Agricultural Science*, 42, 81–91.

Rayudu, E. S., Likhitha, A., Reddy, K. S., & Kumar, G. N. (2022). A study on dragon fruit foliage as natural coagulant and coagulant aid for water treatment. *IOP Conference Series: Earth and Environmental Science*, 982, 012040. doi:10.1088/1755-1315/982/1/012040

Ritcher, C. A., & Azevedo Netto, J. M. (2003). *Tratamento de água: Tecnologia atualizada*. Edgard Blücher.

Shafad, M. R., Ahamad, I. S., Idris, A., & Abidin, Z. Z. A. (2013). A preliminary study on dragon fruit foliage as natural coagulant for water treatment. *International Journal of Engineering Research & Technology*, 2(12), 1057–1063. ISSN: 2278-0181

Shah, K., Chen, J., Chen, J., & Qin, Y. (2023). Pitaya nutrition, biology, and biotechnology: A review. *International Journal of Molecular Sciences*, 24(18), 13986. doi: 10.3390/ijms241813986

Som, A. M., & Wahab, A. F. A. (2018). Performance study of dragon fruit foliage as a plant-based coagulant for treatment of palm oil mill effluent from three-phase decanters. *Bio Resources*, 13(2), 4290–4300.

Som, A. M., Ramlee, A. A., Puasa, S. W., & Hamid, H. A. (2021). Optimisation of operating conditions during coagulation flocculation process in industrial wastewater treatment using *Hylocereus undatus* foliage through response surface methodology. *Environmental Science and Pollution Research*, 30, 17108–17121. doi:10.1007/s11356-021-17633-w

Viessman, W., & Hammer, M. J. (2004). *Water supply and pollution control* (7th ed.). Pearson Prentice Hall.

Yu, W. Z., Gregory, J., Campos, L., & Li, G. (2011). The role of mixing conditions on floc growth, breakage and re-growth. *Chemical Engineering Journal*, 172, 425–430. doi: https://doi.org/10.1016/j.cej.2011.03.098

Authorship contributions

1 – Emili Borges Carlos

Graduated in Agronomy from the Federal Institute of Santa Catarina (IFC)
https://orcid.org/0000-0002-9374-5727 • borges.emili@gmail.com
Contribution: Conceptualization, Methodology, Software, Data curation, Formal analysis, Investigation, Validation, Funding acquisition, Writing - original draft

2 – Suzana Frighetto Ferrarini

PhD in Materials Engineering and Technology from PUCRS
https://orcid.org/0000-0002-8991-8605 • suzana-ferrarini@uergs.edu.br
Contribution: Conceptualization, Validation, Supervision, Project administration, Funding acquisition, Writing - review & editing

3 – Airton Luiz Bortoluzzi

PhD in Agronomy from the Federal University of Viçosa
https://orcid.org/0009-0006-1210-0684 • airton.bortoluzzi@ifc.edu.br
Contribution: Methodology, Validation, Formal Analysis, Resources, Supervision, Funding acquisition

4 – Márcia dos Santos Ramos Berreta

PhD in Geography from the Federal University of Rio Grande do Sul
https://orcid.org/0000-0001-8302-091X • marcia-berreta@uergs.edu.br
Contribution: Resources, Writing - review & editing

5 – Daniela Mueller de Lara

PhD in Environment and Development from the University of Vale do Taquari - UNIVATES
https://orcid.org/0000-0002-2244-1793 • daniela-lara@uergs.edu.br
Contribution: Writing - review & editing

How to quote this article

Carlos, E. B., Ferrarini, S. F., Bortoluzzi, A. L., Berreta, M. S. R., & Lara, D. M. (2025). Use of agricultural waste: pitaya cladode in sustainable treatment of water for human consumption - part 1. *Ciência e Natura*, Santa Maria, 47, e90969. DOI: https://doi.org/10.5902/2179460X90969. Available in: https://doi.org/10.5902/2179460X90969