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JORDANA SOUZA PAULA RISS

TECNOLOGIA SOCIAL PARA O TRATAMENTO DE ÁGUA PARA CONSUMO HUMANO COM COAGULANTE À BASE DE CACTOS RORAIMENSES

BOA VISTA, RR
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Tese apresentada ao Programa de Pós-graduação em Recursos Naturais da Universidade Federal de Roraima, para obtenção do título de doutora em Ciências Ambientais (Recursos Naturais).
Linha de pesquisa: Bioprospecção.

Orientador: Dr. Marcos José Salgado Vital.
Coorientadora: Dra. Ana Paula Folmer Correa.

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Tese apresentada como pré-requisito para a conclusão do curso de doutorado em Ciências Ambientais (Recursos Naturais) da Universidade Federal de Roraima, defendida em 03 de julho de 2023 e avaliada pela seguinte banca examinadora:

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"É necessário dizer que não é a quantidade de informações, nem a sofisticação em Matemática que podem dar sozinhas um conhecimento pertinente, mas sim a capacidade de colocar o conhecimento no contexto"

(Edgar Morin, 2000)

RESUMO

O principal desafio desta pesquisa está relacionado ao fornecimento de água potável para comunidades carentes e/ou residentes em locais de difícil acesso na região Amazônica. A falta de saneamento, o adoecimento pelo consumo de água sem qualidade afeta milhões de brasileiros. Desta forma, desenvolver estratégias seguras, de baixo custo e eficazes para tratar a água de consumo a partir de cactos do lavrado de Roraima, contribuirá para a qualidade de vida das comunidades que não têm acesso à água potável, além de proteger o ambiente, pela diminuição no lançamento de poluentes. Diante disto, o objetivo desta pesquisa, precursora na região, foi desenvolver uma tecnologia social para o tratamento de água para consumo humano, com coagulante à base de cactos roraimenses. Preliminarmente, foi realizado um ensaio para verificar o potencial de coagulação do cacto quanto à turbidez da água do rio Branco. Para desenvolvimento da tecnologia social procedeu-se a caracterização das águas superficiais e subterrâneas na comunidade ribeirinha de Santa Maria do Boiaçu, medindo-se a turbidez, o pH, os coliformes totais e termotolerantes e os ensaios de coagulação em equipamento *Jar Test*, de acordo com o *Standard Methods for the Examination of Water and Wastewater*. Para a prospecção fitoquímica e as atividades biológicas, o extrato etanólico de *Cereus jamacaru* foi avaliado quanto à capacidade antioxidante, determinada pelos métodos de DPPH e ABTS e quanto ao teor de compostos fenólicos totais pela adaptação do método Folin-Ciocalteau. O perfil químico foi analisado pelo método APCI-MS e a toxicidade a partir da CL50 em ensaio agudo com *Artemia salina*. O coagulante natural do cacto *C. jamacaru* do lavrado de Roraima possui ação coagulante para o tratamento da água destinada ao consumo humano, podendo ser utilizado tanto para águas superficiais quanto para subterrâneas, independente da sazonalidade. A tecnologia social produzida com a comunidade ribeirinha de Santa Maria do Boiaçu, a partir do extrato de *C. jamacaru*, demonstrou eficácia na coagulação da água, permitindo o seu consumo e possibilitando que outras comunidades em condição de vulnerabilidade possam produzir o coagulante natural e obter água de qualidade, visto moradores foram treinados e certificados, podendo atuar como multiplicadores. Este fato, além de propiciar qualidade de vida aos moradores, protege o ambiente e contempla dois importantes Objetivos de Desenvolvimento Sustentável proposto pela Organização das Nações Unidas: 3: Saúde e bem-estar e 6: Água potável e saneamento.

Palavras-chaves: Qualidade da água. Saúde humana. Biocoagulante. Amazônia. Estudo Fitoquímico. Comunidades Ribeirinhas.

ABSTRACT

The main challenge of this research is related to the supply of potable water for needy communities and/or residents in places of difficult access in the Amazon region. The lack of sanitation, illness due to the consumption of poor quality water affects millions of Brazilians. In this way, developing safe, low-cost and effective strategies to treat drinking water from cacti from the lavrado of Roraima will contribute to the quality of life of communities that do not have access to drinking water, in addition to protecting the environment, through decrease in the release of pollutants. Given this, the objective of this research, a precursor in the region, was to develop a social technology for the treatment of water for human consumption, with a coagulant based on Roraima cacti. Preliminarily, an assay was carried out to verify the coagulation potential of the cactus in relation to the turbidity of the water in the Branco River. For the development of social technology, surface and groundwater were characterized in the riverside community of Santa Maria do Boiaçu, measuring turbidity, pH, total and thermotolerant coliforms and coagulation tests in Jar Test equipment, according to with the Standard Methods for the Examination of Water and Wastewater. For phytochemical prospecting and biological activities, the ethanolic extract of Cereus jamacaru was evaluated for its antioxidant capacity, determined by the DPPH and ABTS methods, and for the content of total phenolic compounds by adapting the Folin-Ciocalteau method. The chemical profile was analyzed by the APCI-MS method and the toxicity from the LC50 in an acute test with Artemia salina. The natural coagulant of the cactus *C. jamacaru* from the lavrado of Roraima has a coagulant action for the treatment of water intended for human consumption, and can be used for both surface and groundwater, regardless of seasonality. The social technology produced with the riverside community of Santa Maria do Boiaçu, based on the extract of *C. jamacaru*, proved to be effective in coagulating water, allowing its consumption and allowing other vulnerable communities to produce the natural coagulant and obtain quality water, since residents were trained and certified, being able to act as multipliers. This fact, in addition to providing quality of life for residents, protects the environment and includes two important Sustainable Development Goals proposed by the United Nations: 3: Health and well-being and 6: Drinking water and sanitation.

Keywords: Water quality. Human health. Biocoagulant. Amazon. Phytochemical Study. Riverside Communities

SUMÁRIO

1 INTRODUÇÃO

No Brasil, além da demanda por água de qualidade, a escassez de recursos financeiros para os sistemas de saneamento básico tem estimulado pesquisas que aperfeiçoem os processos de coagulação e floculação, assim como o emprego de coagulantes naturais no tratamento da água (RICHTER, 2009). A região com maior abundância e disponibilidade de recursos hídricos é a Amazônica. Entretanto, as condições sanitárias, a drenagem de esgotos e o tratamento de água são precários, agravando o problema da saúde humana com incidência sobre a mortalidade infantil conforme apontou o relatório da “Agenda pela Infância e Adolescência na Amazônia”, do Fundo das Nações Unidas para a Infância (UNICEF, 2018). De acordo com o Sistema Nacional de Informações sobre o Saneamento Básico, no Brasil 34,2 milhões de pessoas não têm acesso à água tratada (SNIS, 2019).

O problema da falta de saneamento básico se intensifica na região Amazônica quando pensamos nas populações que vivem em áreas de difícil acesso, pois a disponibilidade econômica e a complexidade tecnológica de alguns métodos de tratamento de água inviabilizam a implantação em algumas localizações (MELLO, 2018), tornando-se soluções distantes da realidade e cultura local da região. A Tecnologia Social (TS) surge como uma alternativa, capaz de solucionar problemas essenciais, como à demanda por água potável, promovendo, assim, a saúde e melhorias ambientais (MENDOLA, 2019). A TS é definida como um “Conjunto de técnicas, metodologias transformadoras, desenvolvidas e/ou aplicadas na interação com a população e apropriadas por ela, que representam soluções para inclusão social e melhoria das condições de vida” (DAGNINO, 2011, p. 1) tal definição norteará esta pesquisa.

Para o fornecimento de água de qualidade à população e suas atividades cotidianas, a água captada para abastecimento passa por um processo de tratamento nas Estações de Tratamento de Água (ETA). Esse processo consiste basicamente em quatro etapas, a coagulação e a floculação, a decantação, a filtração e pôr fim a cloração e a fluoretação. A coagulação se destaca por ser um processo que envolve a aplicação de produtos químicos que possibilitam a remoção de compostos que estão dissolvidos na água e a desestabilização de suspensões coloidais e sólidos que não podem ser removidos por sedimentação ou filtração. Intimamente ligada à coagulação está à floculação, durante a qual as partículas desestabilizadas pelo coagulante aglutinam-se e formam flocos passíveis de decantação (LIMA JUNIOR, 2018; RICHTER, 2009).

De acordo com Lima Junior e Abreu (2018), os principais coagulantes empregados no tratamento das águas públicas são os sais inorgânicos, tais como sulfato de alumínio, cloreto férrico, sulfato ferroso e policloreto de alumínio. Oladoja et al. (2017) afirmam que os coagulantes à base de alumínio são rotineiramente mais utilizados devido ao seu baixo custo e sua eficiência no tratamento convencional da água.

Durante o tratamento da água, o acúmulo de resíduos de hidróxidos metálicos não biodegradáveis, gerados durante os processos de coagulação e floculação, a alta concentração de lodo que apresenta potencial ecotóxico (OLADOJA et al., 2017) e a relação com patologias que afetam o sistema nervoso central, como demências e doenças de Alzheimer e Parkinson, são alguns dos resultados da aplicação dos coagulantes inorgânicos ao tratamento da água para consumo humano (WALTON, 2013).

Seguindo os princípios da química verde propostos na década de 90, Lima Junior e Abreu (2018) afirmam que o desenvolvimento de coagulantes e floculantes, baseados em matérias-primas naturais biodegradáveis abundantes na natureza, denominados coagulantes naturais ou biocoagulantes, vêm ganhando cada vez mais espaço nas pesquisas voltadas para as tecnologias ambientais. Os coagulantes naturais seguem o conceito de material eco-friendly, aqueles projetados para causar o menor dano natural possível.

Estudar espécies vegetais com potencial de coagulação apresentam grandes vantagens, a saber: alta disponibilidade de matéria-prima, muitas vezes renovável; baixa corrosividade sobre o sistema de distribuição hídrica; diminuição de até cinco vezes do volume de lodo gerado no processo de tratamento da água; em geral, não apresentam riscos à saúde humana e animal e redução de custos e perigos nos processos de tratamento (TEIXEIRA et al., 2017).

Os estudos com cactos destinados ao tratamento de água têm recebido grande atenção, em razão da sua composição química e estrutural visto possuírem nutrientes, proteínas, amilose, ácido málico, resina, vitaminas e celulose (ZARA; THOMAZINI; LENZ, 2012). Porém, pesquisas com a aplicação de cactos no tratamento de água são ainda escassas, sendo essa pesquisa precursora na região.

Neste contexto, o problema desta pesquisa está centrado na possibilidade de que a qualidade de vida de comunidades ribeirinhas amazônicas pode ser melhorada com a adoção de tecnologia social a base de coagulantes naturais, a partir de cactos roraimenses, para o tratamento da água. Para apresentar respostas ao problema norteador desta pesquisa foram feitas as seguintes arguições: i. O coagulante à base do cacto Mandacaru do lavrado de Roraima possui ação coagulante para o tratamento da água destinado ao consumo humano? ii. Há diferença de eficiência entre as concentrações do coagulante e a origem da água a ser tratada? iii. A sazonalidade afeta o desempenho do coagulante natural à base do Mandacaru? iv. O coagulante natural à base de cacto pode ser considerado uma tecnologia social? Assim o objetivo geral desta pesquisa foi desenvolver um coagulante à base de cactos roraimenses para tratar a água destinada ao consumo humano em comunidade ribeirinha da Bacia do rio Branco em Roraima.

De forma sintética, nesta pesquisa foi utilizado o cacto *Cereus jamacaru* De Candolle, popularmente, conhecido como Mandacaru, que compõe a fitofisionomia do lavrado, para avaliar o potencial de coagulação no tratamento da água. Destarte, o estudo foi desenvolvido dentro do contexto Amazônico, considerando a conjuntura ambiental, espacial, temporal e principalmente social, ressatando-se a destacada importância do lavrado de Roraima para a conservação da biodiversidade e dos recursos hídricos. Para o desenvolvimento da tecnologia social a comunidade de Santa Maria do Boiaçu recebeu capacitação para a produção do coagulante natural, que foi certificada pelo Departamento de Ensino do Campus Novo Paraíso do Instituto Federal de Roraima, conforme processo nº 23230.000230.2023-65.

Visando ampliar a disseminação do conhecimento, inclusive agilizando a elaboração da tese, bem como o processo de avaliação pelos membros da banca examinadora, o Programa de Pós-graduação em Recursos Naturais da Universidade Federal de Roraima (PRONAT-UFRR), permite que o discente apresente a tese no formato compacto, a partir dos artigos produzidos, conforme as normas para apresentação de trabalhos técnico-científicos da UFRR, aprovada pela Resolução n.º 08/2017-CEPE/UFRR (UFRR, 2017).

Portanto, esta tese é formada por três artigos, os quais estão organizados seguindo a sequência dos objetivos específicos, proporcionando uma melhor compreensão. Após cada artigo não publicado, estão dispostas as normas para submissão de cada revista científica, para qual o artigo foi submetido, conforme estabelece a referida resolução.

O primeiro artigo, intitulado ***"Effect of amazon cactus (Cereus jamacaru) as a natural coagulant for the removal of turbidity from surface wate"***, teve o objetivo de analisar o potencial de ação do coagulante natural de cactos por meio de um ensaio preliminar. Este artigo foi publicado no Periódico Tchê Química, que no ato da submissão apresentava *Qualis* B1 (2013-2016) na área de Ciências Ambientais. Nesta pesquisa concluiu-se que cacto amazônico *C. jamacaru* demonstra eficácia de coagulação na análise da turbidez da água amostrada.

Para atender o segundo objetivo desta tese, foi elaborado o artigo ***"Social technology for water treatment in a riverine community in the lower branco river region, Roraima, extreme north of Brazil"***, cujo os objetivos foram verificar a eficiência do coagulante à base de cactos em águas superficiais e subterrâneas em duas escalas sazonais; e adaptar o método de obtenção do coagulante natural para ser aplicado em comunidades como Tecnologia Social com capacidade de tratar a água para o consumo humano. Este artigo foi submetido para a Revista Brasileira de Tecnologia Social, que apresenta *Qualis* B1, na área de Ciências Ambientais, conforme quadriênio 2017-2019. A conclusão desta pesquisa demonstra que a tecnologia social produzida junto à comunidade ribeirinha de Santa Maria do Boiaçu tem eficácia na coagulação por meio da análise dos parâmetros de turbidez e pH, sem influência da sazonalidade.

O terceiro artigo, intitulado ***"Phytochemical prospecting and biological activity of the ethanolic extract of cacti from the "lavrado" region of Roraima, Brazil",*** teve como objetivo realizar um *screening* fitoquímico do cacto Mandacaru da região de lavrado do estado de Roraima. Este artigo foi submetido para a Journal Gaia Scientia, cujo *Qualis* de referência é B1 em Ciências Ambientais. Tal estudo revelou 35 compostos secundários no extrato etanólico dos cladódios do cacto *C. jamacaru*, além de fornecer evidências substanciais de que este cacto é uma fonte potente de antioxidantes e não apresenta toxicidade.

Parte dos resultados desta pesquisa foram submetidos ao CATALISA ICT uma iniciativa articulada pelo Sebrae Nacional, com a parceria de entidades do ecossistema de inovação, com o objetivo de acelerar e fomentar negócios inovadores de base tecnológica, para alavancar geração de riqueza e bem-estar para a sociedade. A proposta foi classificada até a segunda fase onde alcançou nota máxima na avaliação do quesito impacto social.

A proposta de produção da tecnologia social envolvendo o extrato do cacto, centralidade desta pesquisa, está participando do Programa Centelha Roraima, uma iniciativa promovida pelo Ministério da Ciência, Tecnologia e Inovações (MCTI) e pela Financiadora de Estudos e Projetos (Finep), em parceria com o Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), com o Conselho Nacional das Fundações Estaduais de Amparo à Pesquisa (Confap), e a Fundação CERTI. Em Roraima, o programa é executado pela Fundação de Amparo à Pesquisa e Inovação de Roraima (FAPERR), e a proposta ocupa a quarta colocação na fase 2 de um total de 3 fases. A etapa atual visa o desenvolvimento de um projeto com foco na viabilidade e no desenvolvimento do empreendimento. O programa Centelha visa estimular a criação de empreendimentos inovadores e disseminar a cultura empreendedora no estado de Roraima.

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2 “EFFECT OF AMAZON CACTUS (*Cereus jamacaru*) AS A NATURAL COAGULANT FOR THE REMOVAL OF TURBIDITY FROM SURFACE WATER”

Disponível no link: https://www.tchequimica.com/Periodico42.pdf

PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

EFEITO DO CACTO AMAZÔNICO (*Cereus jamacaru*) COMO COAGULANTE NATURAL PARA A REMOÇÃO DA TURBIDEZ DE ÁGUAS SUPERFICIAIS

EFFECT OF AMAZON CACTUS (*Cereus jamacaru*) AS A NATURAL COAGULANT FOR THE REMOVAL OF TURBIDITY FROM SURFACE WATER

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RESUMO

Introdução: O Brasil sofre com a falta de saneamento básico e esse fato se intensifica na região Amazônica quando pensamos nas populações vivendo em áreas de difícil acesso. A aplicação de coagulantes naturais surge como uma alternativa promissora, apresenta metodologia simples, de baixo custo, de fácil reprodução e acessível, promovendo a saúde e melhorias ambientais. O uso de coagulantes químicos pode acarretar malefícios ao ambiente e à saúde humana. **Objetivo:** Portanto, o objetivo desse estudo foi avaliar o efeito de coagulação de uma espécie de cacto amazônico aplicado ao tratamento de água para consumo humano. **Métodos:** Para o estudo, coletou-se cerca de 500 gramas da parte aérea do *Cereus jamacaru* às margens da BR 174 na região do lavrado de Roraima. No laboratório, foram retirados os espinhos, o material vegetal foi lavado, cortados a uma espessura de um centímetro, secos em estufa a 60 °C por 36 horas, triturados em liquidificador e peneirados até a obtenção de um pó, o qual foi testado como coagulante natural. A água utilizada no estudo foi coletada do Rio Branco no município de Boa Vista-RR e caracterizada quanto a sua turbidez inicial. **Resultados:** A dosagem de 0,2g do coagulante natural de cacto apresentou significativa redução na turbidez da água de estudo, deixando-a dentro dos padrões de potabilidade estabelecidos para as água subterrâneas. **Discussão:** A coagulação no contexto sanitário é evidenciada em razão da remoção de partículas microscópicas associadas aos microrganismos patogênicos, normalmente encontrados nas águas brutas e com velocidade de sedimentação muito reduzida. Substituir substâncias químicas poluidoras por coagulantes naturais no tratamento da água para consumo humano contribui para a qualidade de vida. **Conclusão:** O cacto amazônico *Cereus jamacaru* demonstrou eficácia de coagulação para a análise do parâmetro turbidez da água para consume humano.

Palavras-chave: *Qualidade da água, Saúde humana, Biocoagulante*

ABSTRACT

Background: Brazil suffers from a lack of basic sanitation in many regions, intensified in the Amazon region due to its difficult access. The application of natural coagulants is a promising alternative since it eliminates the use of chemicals, is a simple, low-cost method that is easy to reproduce, and is accessible to any community, thus promoting health and environmental improvements. On the other hand, the use of chemical coagulants can cause harm to the environment and human health. **Aim:** Therefore, the objective of this study was to evaluate the coagulation effect of a species of Amazonian cactus applied in the treatment of water for human consumption. **Methods:** For the study, about 500 grams of the aerial part of the *Cereus jamacaru* was collected on the banks of the BR 174 in the region of Roraima. The spines were removed in the laboratory, the plant material was washed, cut to a thickness, dried in an oven at 60 °C for 36 hours, then ground and sieved until obtaining a powder, which was tested as a natural coagulant. The water used in the study was collected from the Branco River in Boa Vista, Roraima, and characterized its initial turbidity. **Results:** The dosage of 0.2g of the natural cactus coagulant showed a significant reduction in the turbidity of the study water, leaving it within the potability standards established for groundwater. **Discussion**: Coagulation in the sanitary context is evidenced by the removal of

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microscopic particles associated with pathogenic microorganisms, normally found in raw water and with very low sedimentation speed. Replacing polluting chemical substances with natural coagulants in the treatment of water for human consumption contributes to the quality of life. **Conclusion:** The Amazonian cactus *Cereus jamacaru* demonstrated coagulation efficiency for analyzing the turbidity parameter of water for human consumption.

Keywords: *Quality water, Human health, Biocoagulant*

1. INTRODUCTION:

According to the National Information System on Basic Sanitation, 39.4 million Brazilians do not have access to treated water (BRASIL, 2018). The problem of lack of basic sanitation intensifies in the Amazon region of Brazil, principally due to its difficult access areas. In addition, economic viability and the complexity of the operation may make it impossible to implement specific water treatment methods in some locations (MELLO, 2018). To supply good quality water to the population for their daily activities, water intended for supply goes through a treatment process in water treatment plants (ETA). The conventional and most commonly used treatment in Brazilian ETAs consists of four stages: coagulation and flocculation, decantation, filtration, and finally, chlorination and fluoridation. Coagulation stands out as a process involving the application of chemicals that allow the removal of dissolved compounds in the water and the destabilization of colloidal suspensions and solids that cannot be removed by sedimentation or filtration. Closely linked to coagulation is flocculation, during which particles destabilized by the coagulant coalesce and form flakes amenable to decantation (LIMA JUNIOR, 2018; RICHTER, 2009).

Following the principles of green chemistry proposed in the 90s, Lima Junior and Abreu (2018) state that the development of coagulants and flocculants, based on biodegradable natural raw materials abundant in nature, called natural coagulants or biocoagulants, has been gaining more and more space in research focused on environmental technologies since natural coagulants follow the concept of eco-friendly material, those designed to cause the least harm to nature. Therefore, studies with cacti that can be used for water treatment have received great attention due to their chemical composition since they have nutrients with coagulation potential (ZARA; THOMAZINI; LENZ, 2012). Furthermore, during water treatment, the accumulation of residues of non-biodegradable metal hydroxides generated during coagulation and flocculation processes, the high concentration of sludge that presents ecotoxic potential (OLADOJA *et al*., 2017), and the relationship with pathologies that affect the central nervous system, such as dementia and Alzheimer's and Parkinson's diseases, are some of the results of the application of chemical coagulants to the treatment of water for human consumption (CHUA *et al*., 2019; FERMINO *et al*., 2017; WALTON, 2013). Such hazards make studies with natural coagulants advantageous as there is a high availability of raw materials, are often renewable, have low corrosiveness on the water distribution system, and there is a decrease of up to five times in the volume of sludge generated in the water treatment process. In addition, they do not present risks to human and animal health, and there is a significant reduction in costs and dangers in the treatment processes (TEIXEIRA *et al*., 2017).

Mandacaru (*C. jamacaru*) is a cactus native to Brazil, abundant in the northeast region of the country (ZARA; THOMAZINI; LENZ, 2012) and found in the Roraima field (OLIVEIRA, 2016; PASSOS, 2019). According to Cavalcante (2013), some metabolic and structural adaptations are necessary, so that species of the cactus family can survive in different environments, including adverse ones. Studies with cactus intended for water treatment have received significant attention due to their chemical and structural composition since they contain nutrients, proteins, amylose, malic acid, resin, vitamins, and cellulose (ZARA; THOMAZINI; LENZ, 2012). However, research on the application of cactus in water treatment is still scarce, and it is worth mentioning that no records were found about this application with species from the Amazon region of Brazil.

This study was developed in the context of the Brazilian Amazon and considered the environmental, spatial, temporal, and mainly social conjuncture. The state of Roraima is located in the northwest of the northern region of Brazil and is predominated by rainforest vegetation; however, in the central-eastern region, there is a huge strip of farmland known as "lavrado", a local name given to the savanna region. The farmland of Roraima is highly important for conserving biodiversity and water resources; therefore, the cactus *Cereus jamacaru* De Candolle (popularly known as Mandacaru) was studied for treating water. Furthermore, due to its polymers, which have coagulating and flocculating action, it is believed that the cactus is not only effective but also safer in the treatment of water, thus promoting lower impacts on the environment and human health. Therefore, the objective of this study was to evaluate the coagulation effect of a species of Amazonian cactus applied to water treatment for human consumption.

2. MATERIALS AND METHODS:

Raw water samples from the Branco River were collected near the extraction point used by the Water and Sewage Company of Roraima (CAER), located in the city of Boa Vista, state of Roraima, Brazil, under geographic coordinates 760511 E, 312928 N. The collection was carried out in March 2021 in a period of drought in the State of Roraima. 12 liters of water were collected, stored in amber glasses, placed in a styrofoam box containing ice for cooling and transported to the laboratory of the Federal University of Roraima. Coagulation assays were performed on the same day of collection. Water characterization before and after treatment was performed by measuring turbidity (Akso TU430) based on the 20th Standard Methods for the Examination of Water and Wastewater (APHA; AWWA; WEF, 2017).

2.1. Preparation of the natural coagulant

The natural coagulant (NC) was prepared with 500 grams (g) of the aerial part of *C. jamacaru*, which was collected in the agricultural region of Roraima. First, the spines of the plant material were removed and discarded, and then the cactus was washed under running water, cut into pieces of about 1 centimeter (cm), and placed on trays (Figure 1a). These were then placed in an oven at 60 ºC for drying (MILLER *et al*., 2008; OTHMANI *et al*., 2020).

After drying, the cactus pieces were ground in a household blender and sieved to provide a powder (Figure 1b) with particles of about 300 micrometers (µm) in diameter. This powder was stored in a sealed container, dated and identified, and kept in a refrigerator until the tests were performed using the jar test equipment.

2.2. Coagulation test

The coagulation assay was performed using jar test equipment (Afakit AT-700) with six jars with a blade speed regulated for two mixing regimes: fast (150 rpm for three minutes); slow (60 rpm for 17 minutes); plus a sedimentation time of 30 minutes with the equipment turned off (Table 1). In the jars, 400 milliliters (mL) of raw water were used according to the adapted methodology of Zara *et al*. (2012).

The dosages of the natural coagulant of cactus and the aluminum sulfate (control) were determined according to values obtained in the literature and in the pre-assays of this study. They were 0.032 g of aluminum sulfate (Zara *et al*., 2012) and 0.01, 0.02, 0.04, 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 g of natural cactus coagulant (ORTIZ; ASTUDILLO; MARTÍNEZ, 2013; FEDALA *et al*., 2015), which were applied directly to the 400 mL of water contained in individual jars. At the end of the coagulation assay, samples of the treated water were collected from each jar with a 20 mL graduated pipette, and a new turbidity measurement was performed.

Table 1. *Stages and rotation speeds and duration for each step of the coagulation assay.*

Stages	Rotation/Duration
Rapid mixing	150 rpm/3 minutes
Slow mixing	60 rpm/17 minutes
Sedimentation	0/30 minutes

3. RESULTS AND DISCUSSION:

3.1. Results

The raw water used in the coagulation test showed initial turbidity of 23 turbidity units (NTUs). After this test, a new turbidity measurement was performed (Table 2). The potability standard for human consumption water is established by Ordinance No. 888, of May 4, 2021, by the Brazilian Ministry of Health (BRASIL, 2021) and has a maximum limit of 5 NTUs established as a standard in the turbidity parameter of the distribution network.

The decreased efficacy of turbidity removal with increased dosage of the natural coagulant (Figure 2) demonstrated in this study corroborates the results of Pichler *et al*. (2012), who used the mucilage of cacti *Opuntia ficus-indica* in water treatment and observed that, by increasing the dose of mucilage, after sedimentation of the flakes, the turbidity of the supernatant also increased.

3.2. Discussion

Although the use of natural coagulants is a sustainable alternative for treating water for human consumption, the application of forms, such as powders, mucilage, or unpurified extracts, directly in the water to be treated leads to an increase in organic matter, thus leaving the water more turbid.

Choy *et al*. (2014) attribute the increase in organic matter to the presence of lipids, biomolecules that do not participate in the coagulation process. Although it was not possible to perform quantification tests of organic matter, this effect can be observed when verifying the initial turbidity of 23 NTUs of the water used in this study with the highest coagulant dosage of 0.5 g of cactus powder that presented the lowest efficiency for removal and left the water with a greenish appearance. However, it is possible to improve the treated water quality using filters, considering that the flakes formed by biomolecules are usually large and easily retained and do not require more advanced filtration systems (PICHLER *et al*., 2012).

Unlike some studies, which demonstrated that the higher the turbidity of the water to be treated, the better the efficiency of natural coagulants, the effect observed in the present study was satisfactory for the sample of water with low turbidity (23 NTUs). In a comparative study with aluminum sulfate, Pichler, Young, and Alcantar (2012) obtained excellent results with the cactus of the genus *Opuntia* by demonstrating that the same turbidity removal efficiency could be obtained with the cactus using a dosage 300 times lower than that of the chemical coagulant.

Pritchard *et al*. (2010) used a natural coagulant based on *Moringa oleifera* seed to treat water with a turbidity of 40 NTUs and 200 NTUs, and the removal efficiency at the end of treatment was 50% and 90%, respectively. A possible justification for this behavior lies in the fact that both *Moringa oleifera* and cacti are considered polyelectrolytes, i.e., they are flocculating polymers with different ionic charges that act in the formation of flakes and assist in coagulation.

For Baghvand *et al*. (2010), low turbidity waters have a small amount of colloidal matter, i.e., this lower concentration of colloids suspended in water limits the contact rate between particles and flocculating polymers, thus hindering the coagulation process and consequently the performance of the coagulant. Therefore, an alternative for treating low turbidity waters is the addition of synthetic turbidity in order to create the formation of heavier flakes, which settle more easily.

4. CONCLUSIONS:

The Amazonian cactus *C. jamacaru* demonstrated coagulation efficacy in the analysis of the turbidity of the sampled water. Replacing polluting chemicals with natural coagulants in water treatment for human consumption contributes to the quality of life by helping communities that do not have access to clean water and protecting the environment. It is possible to suggest the execution of new studies that seek to perform other tests of the physicochemical parameters and the zeta potential to guarantee the effectiveness and safety of cactus application as a natural coagulant for the treatment of water for human consumption.

5. DECLARATIONS

5.1. Study Limitations

The study is limited to the sample size and the period of the collection of the samples.

5.2. Acknowledgements

We thank the Postgraduate Program in Natural Resources at the Federal University of Roraima and the Novo Paraíso Campus of the Federal Institute of Roraima, for supporting the research.

5.3. Funding source

The authors funded this research.

5.4. Competing Interests

There are no potential conflict of interest in this publication.

5.5. Open Access

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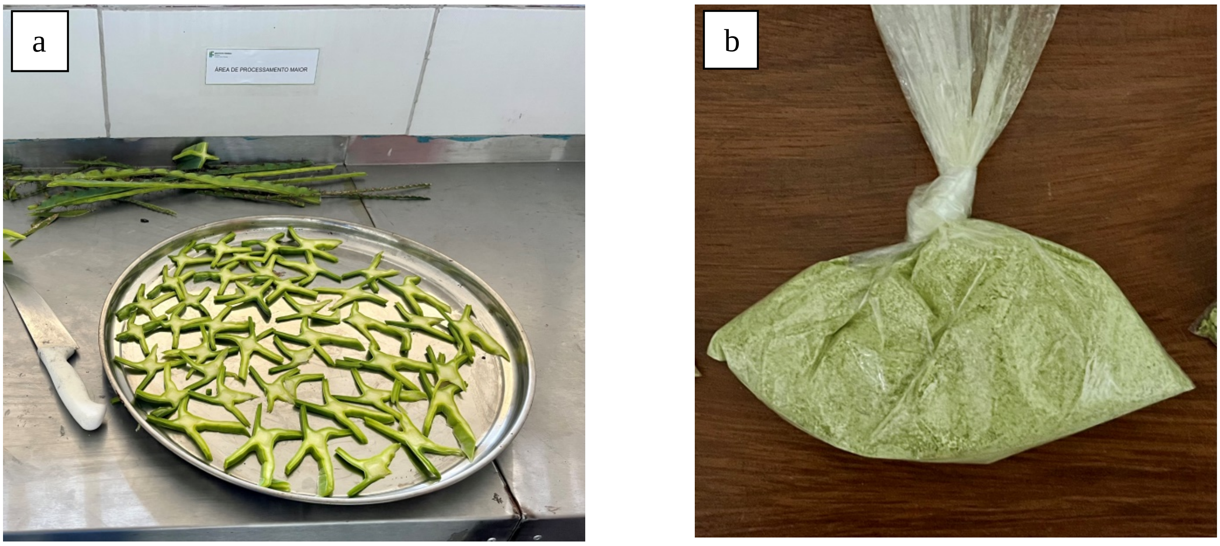


Figure 1. *a.Plant material processing. b. Coagulant powder.* ***Source:*** *the authors*

Table 2. *Turbidity removal values for each dosage and coagulants used.*

Initial turbidity of water sample (NTUs)	Dosage of coagulants (g)	Turbidity after application of coagulants (NTUs)
23	0.032 g aluminum sulphate (control)	2.5
	0.01 g of cactus NC	5.24
	0.02 g of cactus NC	4.91
	0.04 g of cactus NC	4.5
	0.05 g of cactus NC	4.43
	0.1 g of cactus NC	3.49
	0.2 g of cactus NC	2.49
	0.3 g of cactus NC	2.80
	0.4 g of cactus NC	3.99
	0.5 g of cactus NC	7

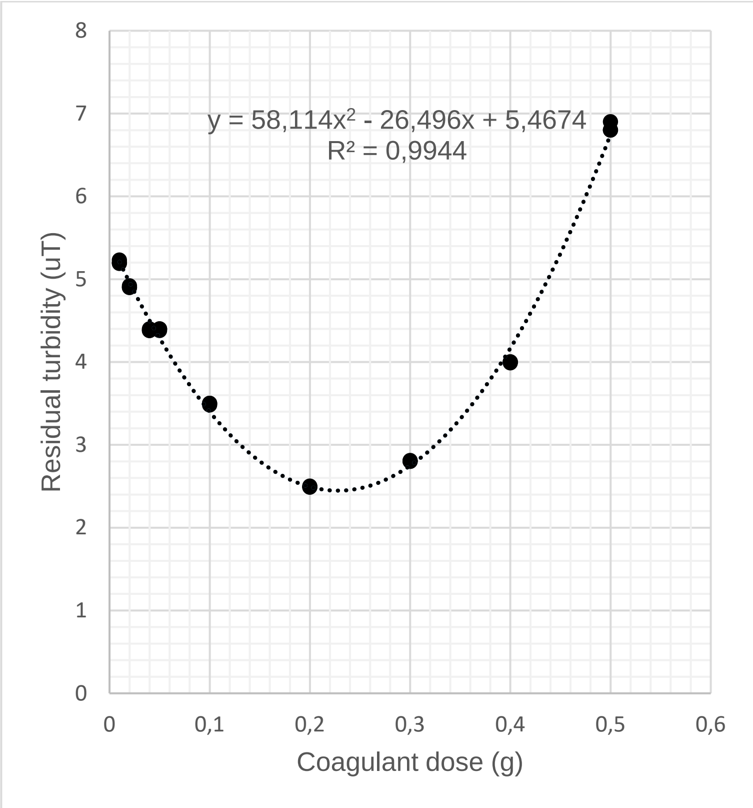
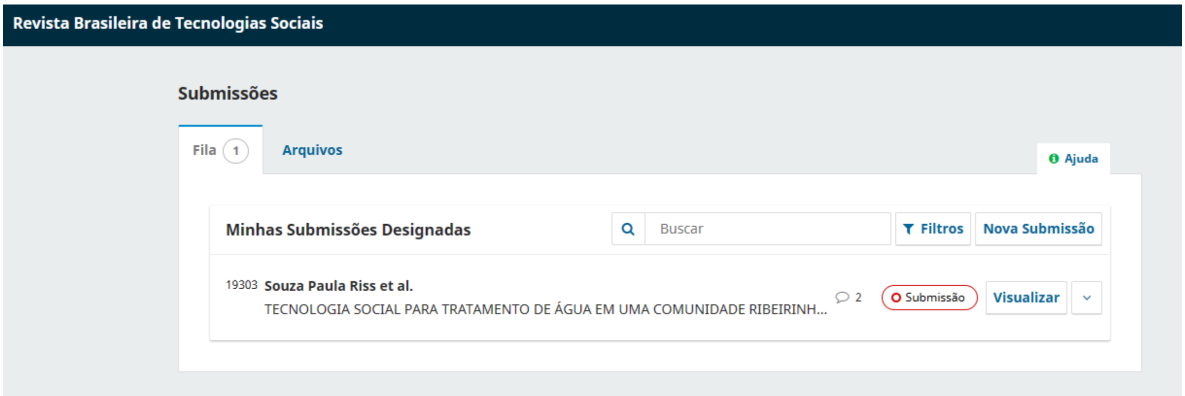
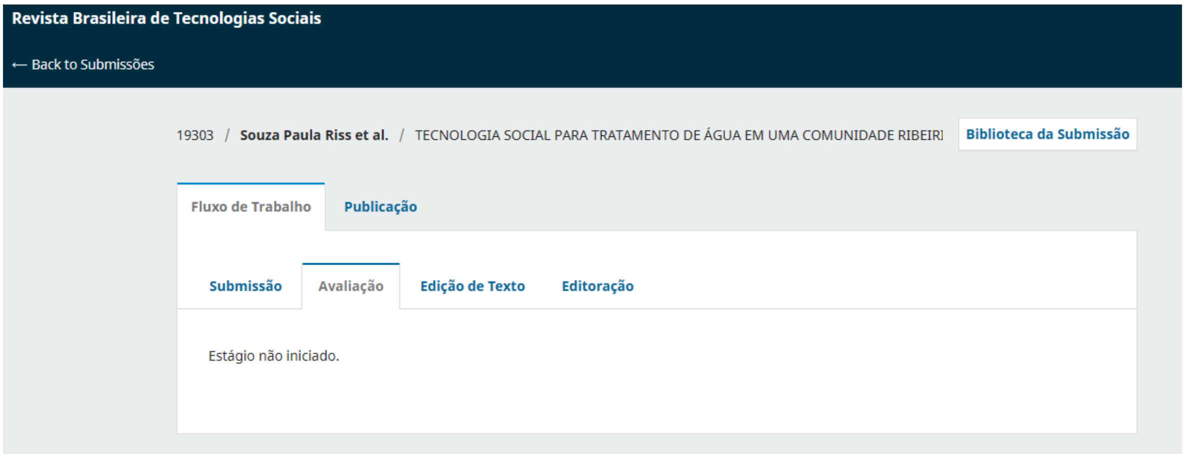


Figure 2. *Removal of turbidity vs. the dosage of coagulants.* ***Source:*** *the authors*

3 "SOCIAL TECHNOLOGY FOR WATER TREATMENT IN A RIVERINE COMMUNITY IN THE LOWER BRANCO RIVER REGION, RORAIMA, EXTREME NORTH OF BRAZIL"





Social technology for water treatment in a riverine community in the Lower Branco River Region, Roraima, Extreme North of Brazil

Jordana Souza Paula Riss, Leovergildo Rodrigues Farias, Glécio Ísavo Araújo, Pedro Aurélio Costa Lima Pequeno, Marcos José Salgado Vital

Abstract - Brazil suffers from the problem of lack of basic sanitation, and this fact is intensified in the Amazon region, as a large part of the population lives in areas of vulnerability. The use of chemical coagulants causes harm to the environment and human health. The application of natural coagulants emerges as a promising alternative, as it dispenses with the use of chemicals, presents a simple, low-cost, easy-to-reproduce methodology that is accessible to any community, promoting health and environmental improvements. The objective of this study was to produce a natural coagulant based on Amazonian cacti to treat water intended for human consumption in a riverside community. For the study, about 500 grams of the aerial part of *Cereus jamacaru* was collected in the community of Santa Maria do Boiaçu-RR. The thorns were removed, and the cactus was washed, cut, accommodated in trays and taken to the sun. After drying, the cactus pieces were crushed and sieved. The water samples for the study were collected at 3 points and the treatability test was carried out in the laboratory. Statistical analyzes revealed that the natural cactus-based coagulant is an efficient social technology for the treatment of groundwater and surface water.

Keywords: Potability, Amazon, Water quality, Riverine, Cacti.

Tecnologia social para tratamento de água em uma comunidade ribeirinha na Região do Baixo Rio Branco, Roraima, Extremo Norte do Brasil

Resumo - O Brasil sofre com o problema da falta de saneamento básico, e esse fato se intensifica na região Amazônica, pois uma grande parte da população vive em áreas de vulnerabilidade. O uso de coagulantes químicos causa malefícios ao ambiente e à saúde humana. A aplicação de coagulantes naturais surge como uma alternativa promissora, pois dispensa o uso dos químicos, apresenta metodologia simples, de baixo custo, de fácil reprodução e acessível a qualquer comunidade, promovendo saúde e melhorias ambientais. O objetivo desse estudo foi produzir um coagulante natural à base de cactos amazônicos para tratar a água destinada ao consumo humano em uma comunidade ribeirinha. Para o estudo, coletou-se cerca de 500 gramas da parte aérea do *Cereus jamacaru* na comunidade de Santa Maria do Boiaçu-RR. Os espinhos foram removidos, e o cacto foi lavado, cortado, acomodados em bandejas e levados ao sol. Após a secagem, os pedaços de cactos foram triturados e peneirados. As amostras de água para estudo foram coletadas em 3 pontos e realizado o ensaio de tratabilidade em laboratório. As análises estatísticas revelaram que o coagulante natural à base de cacto é uma eficiente tecnologia social para o tratamento de águas subterrâneas e superficiais.

Palavras-chaves: Potabilidade. Amazônia. Qualidade de água. Ribeirinho. Cactos.

Introduction

Difficulties in accessing water are not always related to water scarcity. The region with the greatest abundance and availability of water resources is the Amazon, especially taking into account the low population density. However, sanitary conditions, drainage of sewage and water treatment are poor, thus aggravating the problem of human health and causing an impact on infant mortality, as pointed out in the report of the "Agenda for Childhood and Adolescence in the Amazon", of the United Nations Children's Fund (UNICEF, 2018). According to the National Information System on Basic Sanitation, one in every 6 Brazilians do not have access to treated water (SNIS, 2019).

The problem of lack of basic sanitation is intensified in the Amazon region when one considers the populations living in areas of difficult access, since the cost and technological complexity of some water treatment methods make implementation in some locations unfeasible (MELLO, 2018) and, thus, a far cry from the reality and local culture of the region. Due to the custom that Amazonian communities have of inhabiting the banks of rivers, or near streams and water sources, this situation of lack of water is alleviated, but low access to good quality water is a reality that is experienced in the region (GOMES et al., 2021).

Social technology (ST) emerges as an alternative that is capable of solving essential problems, such as the demand for drinking water, and can promote health and environmental improvements (MENDOLA, 2019). ST is defined as any low-cost product, technique or method that can be easily reproduced and applied, and which presents solutions for social transformation (DOMINGOS; RIBEIRO, 2015; BATISTA et al., 2021).

For the supply of quality water to the population for its daily activities, the water collected for supply goes through a treatment process at water treatment plants (WTP). This process basically consists of the steps of coagulation and flocculation, decantation, filtration and ends with chlorination and fluoridation. Coagulation is a process that involves the application of chemicals that allow an accelerated removal of compounds that are dissolved in water and the destabilization of colloidal suspensions and solids that cannot be removed by sedimentation or filtration. Closely linked to coagulation is flocculation, during which the particles destabilized by the coagulant agglutinate and form flakes that are capable of settling (LIMA JUNIOR, 2018; RICHTER, 2009).

The importance of coagulation in the sanitary context is evidenced by the removal of microscopic particles associated with pathogenic microorganisms, which are usually found in raw water and have a very reduced sedimentation rate (LIBÂNIO, 2010). According to Lima Junior and Abreu (2018), the main coagulants used in the treatment of waters for public use are inorganic salts, such as aluminum sulfate, ferric chloride, ferrous sulfate and aluminum polychloride. Oladoja et al. (2017) affirm that aluminum-based coagulants are more routinely used due to their low cost and efficiency in conventional water treatment. However, there is always a negative effect in the use of these chemical coagulants, for example, the toxicity of aluminum ions to aquatic life when in concentrations greater than 50 µg/L (LIMA; ALMEIDA; VICENTINI, 2020), as well as a possible relationship with pathologies that affect the central nervous system, such as dementia, Alzheimer’s and Parkinson’s, which are caused by excessive use of aluminum salts (ANG; MOHAMMAD, 2020) The damage done to public health and aquatic life has therefore motivated researchers to explore greener and more sustainable water treatment technologies (LIMA; ALMEIDA; VICENTINI, 2020).

Natural coagulants achieve a treatment efficiency that is analogous to chemical coagulants (KARANJA; FENGTING; NG’ANG’A, 2017). Multiple studies have sought to establish the effectiveness of cacti as a biocoagulant, and the species *Opuntia ficus-indica, Opuntia dillenii* and *Opuntia stricta* are the best known and studied. Cacti are present in all major Brazilian biomes: Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal (ZAPPI; TAYLOR, 2020). They are also abundant in the northeastern region of Brazil (ZARA; THOMAZINI; LENZ, 2012), and in the north in the state of Roraima (OLIVEIRA, 2016; PASSOS, 2019).

According to Karanja et al. (2017), the use of cactus as a coagulant first requires an overview of its efficacy levels and optimal conditions of use, especially with regard to pH, and the research of Beyene et al. (2016) demonstrates the potential of powdered cactus for removing turbidity, a fact that led the authors to suggest its use in water treatment.

This study was developed within the Amazonian context and considers the environmental, spatial, temporal and especially social conjuncture. Therefore, the cactus *Cereus jamacaru* De Candolle, popularly known in the region as “mandacaru”, which makes up the phytophysionomy of the area (OLIVEIRA, 2016; PASSOS, 2019), was used to evaluate its coagulation potential in water treatment. The ST proposal of this research consisted in the production of a natural coagulant based on the mandacaru cactus that was initially bench tested in the laboratory by analyzing the turbidity parameter. Then, the preparation technique was adapted to the material resources available in the riverine community of Santa Maria do Boiaçu, located in the lower Branco River region, Roraima, extreme north of Brazil. This adaptation aimed at simplifying the preparation, and thus enable the production and application of the coagulant by the community. In January 2022, the invitation to the community was made official and a workshop on good practices in the production of natural coagulant was held. The first water collections were carried out in three catchment points by the community; these being two wells and the banks of the river. The physicochemical parameters analyzed were pH, turbidity, and microbiological parameters for total and fecal coliforms.

The guiding questions of this research are i) Does the coagulant based on the mandacaru cactus produced by the community have sufficient coagulant action for the treatment of water intended for human consumption? (ii) Is there a difference in efficiency between the concentrations of the coagulant and the source of the water to be treated? and iii) Does seasonality affect the performance of mandacaru-based natural coagulant?

In order to obtain an easily replicated social technology, the objective of this research was to produce a coagulant based on cacti from Roraima to treat water destined for human consumption in a riverine community of the Branco River basin in Roraima.

Materials and methods

Study area

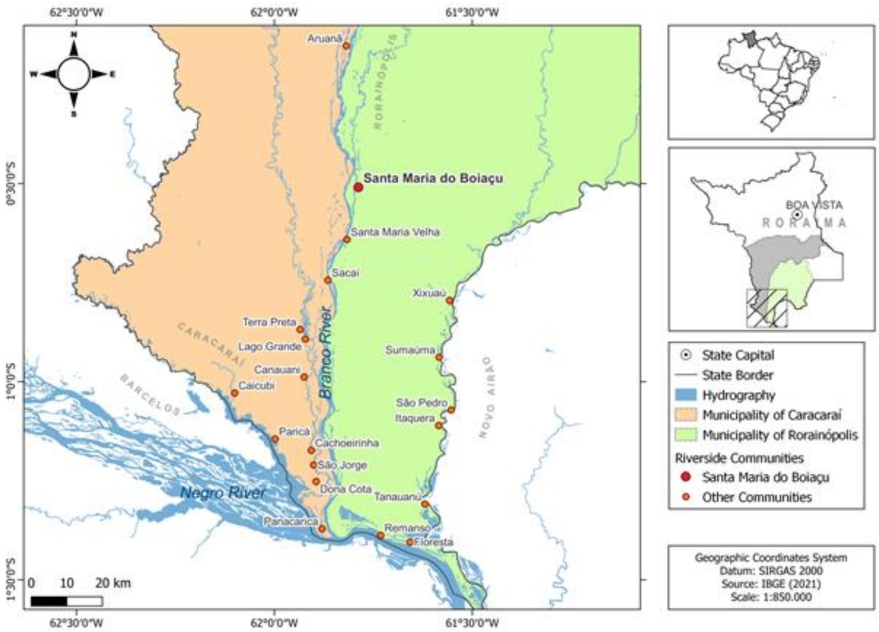
The study was developed in the riverine community of Santa Maria do Boiaçu, which is located in the lower Branco River region, on the left margin of the Branco River, in the municipality of Rorainópolis, state of Roraima (00° 30’ 33” N, 61° 47’ 19” W) (RORAIMA, 2010). The lower Branco River region, located on the southern borders of the state of Roraima with the northwest of the state of Amazonas, is a region of difficult access, as there are no roads, and boats are the most used means of transport to reach the riverine community of Santa Maria do Boiaçu (CAVALCANTE et al., 2020). The region is composed of 20 communities that are part of the municipalities of Rorainópolis and Caracaraí (Figure 1).

The communities that are located on the right margin of the river belong to the municipality of Caracaraí and those located on the left margin belong to the municipality of Rorainópolis. In December 2021, the first telephone contact was made with the president of the Community Fund of the District of Santa Maria do Boiaçu in order to present the research proposal to the entire community. In January 2022, a letter was sent to the leadership officializing the invitation to the community to participate in the workshop on the production of a natural coagulant based on cacti for water treatment, with the inclusion of 15 participants which, after training for the production of natural coagulant, were certified by the Federal Institute of Roraima.

Of the 15 people who participated in the natural coagulant production workshop, 11 were female and 4 were male, including housewives, fishermen, doctors, teachers, students and farmers with an average age of 32 years. Participants were nominated by the president of the community in order to include at least one member of each family residing in Santa Maria do Boiaçu. On January 14, 2022, in the morning, the community was introduced to the team and the project. During the afternoon, the production of the coagulant was started, which consisted of 3 phases: cutting, drying and grinding. For 3 days, the participants followed the drying step in the sun and on the fourth day, the crushing step was performed. Participants also followed the stage of collecting water from the community's three supply points, two wells and the river.

There are three main water sources that supply the community of Santa Maria do Boiaçu; two artesian wells and the Branco River itself. The community does not have a water treatment plant, i.e., there is no quality control system for the water consumed by the people who live there.

Figure 1 - Map of the lower Branco River region, showing the community of Santa Maria do Boiaçu, Roraima



Source: Adaptação IBGE (2021)

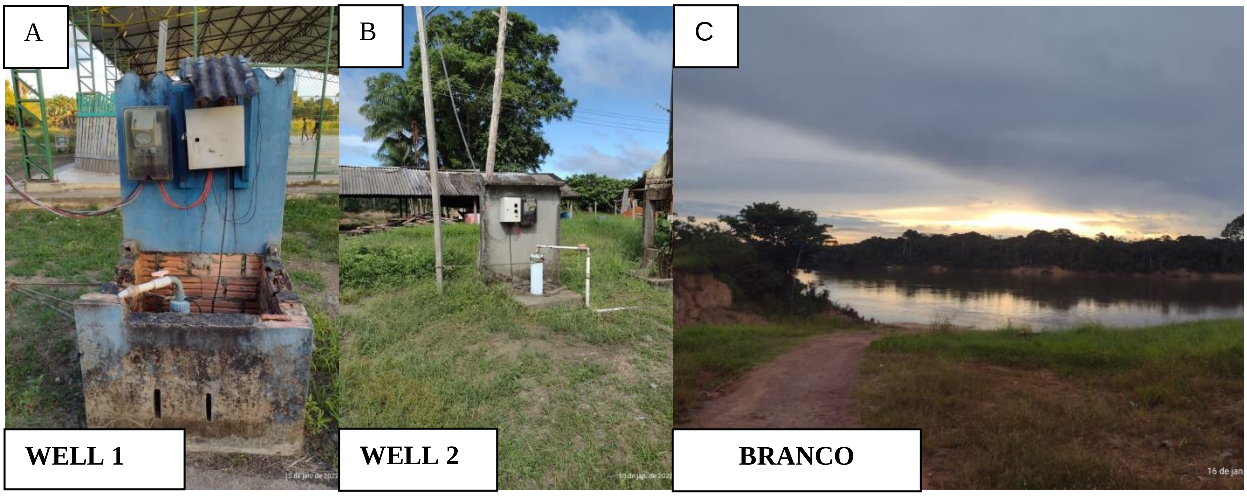
Preparation of the social technology together with the community

To obtain the powdered cacti that was used as a natural coagulant, we used the methodology adapted from that proposed by Miller et al. (2008) and by Othmani et al. (2020). The natural coagulant was prepared with 500 g of the aerial part of the mandacaru cactus collected in the community of Santa Maria do Boiaçu. The thorns of the plant material were removed with a knife and discarded. Then, the cactus was washed under running water, cut into pieces of about 1 cm, placed on trays and left in the sun for three days. After drying, the cactus pieces were ground in a household blender and/or mills and sieved with the help of sieves. This powder was stored in a clean, hermetic container, dated and identified, until the completion of the laboratory treatability tests using the jar test.

Assessment of water quality in the community

The initial assessments of water quality were carried out at the three points of water collection for consumption used by the community, two groundwater wells that here are named Well 1 and Well 2, and the banks of the Branco River (surface water) (Figure 2). Two collections were performed, during the dry and rainy periods, in order to assess whether seasonality influences the coagulation process. The first collection was carried out on January 19th, 2022 after the production of the natural coagulant by the community; the second on June 16th, 2022.

Figure 2 – Water supply sources and sample collection sites in the community of Santa Maria do Boiaçu.



Source: Riss

The surface and groundwater were characterized by measuring turbidity using a portable turbidimeter (Hanna, Hi93703c), pH, with pH meter (Del Lab DLA-PH) and total and fecal coliforms (COLIFORMESBAC). For all collections, the Standard Methods for the Examination of Water and Wastewater (APHA, 2017) were used as a basis.

Sample collection

A total of twelve liters of water samples were collected from each of the three points. These were stored in amber bottles, packed in a thermal box containing ice for refrigeration and then transported to the laboratory at the Federal Institute of Roraima, for testing.

Coagulation test

The coagulation test was performed in triplicate for the three collection points using jar test equipment (Alfakit, AT-700) comprising six jars with the paddle speed regulated in two mixing gradients: fast (150 rpm for three minutes); slow (60 rpm for 17 minutes). The sedimentation time was 30 minutes with the equipment turned off, and used 400 milliliters (mL) of raw water, according to methodology adapted from Zara et al. (2012).

The dosages of the cactus-based natural coagulant were determined according to values obtained in the literature and in pre-assays of this study. Concentrations of 0.01, 0.02, 0.04, 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 g of natural cactus coagulant (VILLABONA ORTIZ; ASTUDILLO; MARTÍNEZ, 2013; FEDALA et al., 2015) applied directly to the 400 mL of water contained in individual jars. At the end of the coagulation test, samples of the treated water were collected from each of the jars with the aid of a 20 mL graduated pipette and a new turbidity and pH measurement was performed to verify the effect of the natural coagulant on the samples.

Results and discussion

Studied water

Brazilian Ordinance No. 888/2021 defines water for human consumption as drinking water intended for ingestion, preparation and production of food and personal hygiene, regardless of its origin (BRASIL, 2021). Therefore, it must meet the minimum potability standards and be within physicochemical and microbiological parameters presented in Table 1.

Table 1 - Parameter values established by Ordinance No. 888/2021 regarding the quality of water intended for human consumption

Parameter	Maximum values permitted (MVP)	Unit
Turbidity (surface water)	Up to 5.0	uT
Turbidity (groundwater)	Up to 1.0	uT

pH	6-9	-
Thermotolerant coliforms	Absent in 100 mL	-

Source: Adapted from Brasil (2021).

The raw water samples from the Branco River, and from well 1 and well 2 showed different values of initial pH and initial turbidity for the different collection seasons and the absence of coliforms, as shown in Table 2. During the dry and rainy season, the water from the Branco River and from one of the wells (Point 1) that supplies the community did not meet the minimum standard for the turbidity parameter established by Ordinance No. 888/2021, though they did present initial pH within the standards.

Table 2 – Values of initial turbidity, initial pH and coliforms during different seasons in the riverine community of Santa Maria do Boiaçu, Roraima.

Sample	Season	Initial tubidity (uT)	Initial pH	Coliforms
Branco River	dry	26.17	7.3	Absent
Point 1 (well)		5.99	6.57	Absent
Point 2 (well)		0.39	7.3	Absent
Branco River	rainy	7.18	6.87	Absent
Point 1 (well)		0.67	6.86	Absent
Point 2 (well)		0.41	6.88	Absent

Source: Riss

Coagulation test

Figure 3a shows the efficiency of turbidity removal according to the coagulation test using different concentrations of the cactus-based coagulant. It is noted that by increasing the concentration of the natural coagulant the turbidity increases. This behavior of a decrease in turbidity removal efficacy with the increasing dosage of the natural coagulant demonstrated in this study corroborates the results of Pichler et al.

(2012), who used cactus mucilage in water treatment and observed that when they increased the dose of mucilage, the turbidity of the supernatant after sedimentation of the flakes also increased. Although the use of natural coagulants is a sustainable alternative for treating water for human consumption, the application of forms, such as powders, mucilage or unpurified extracts, directly in the water to be treated leads to an increase in organic matter, which leaves the water more cloudy.

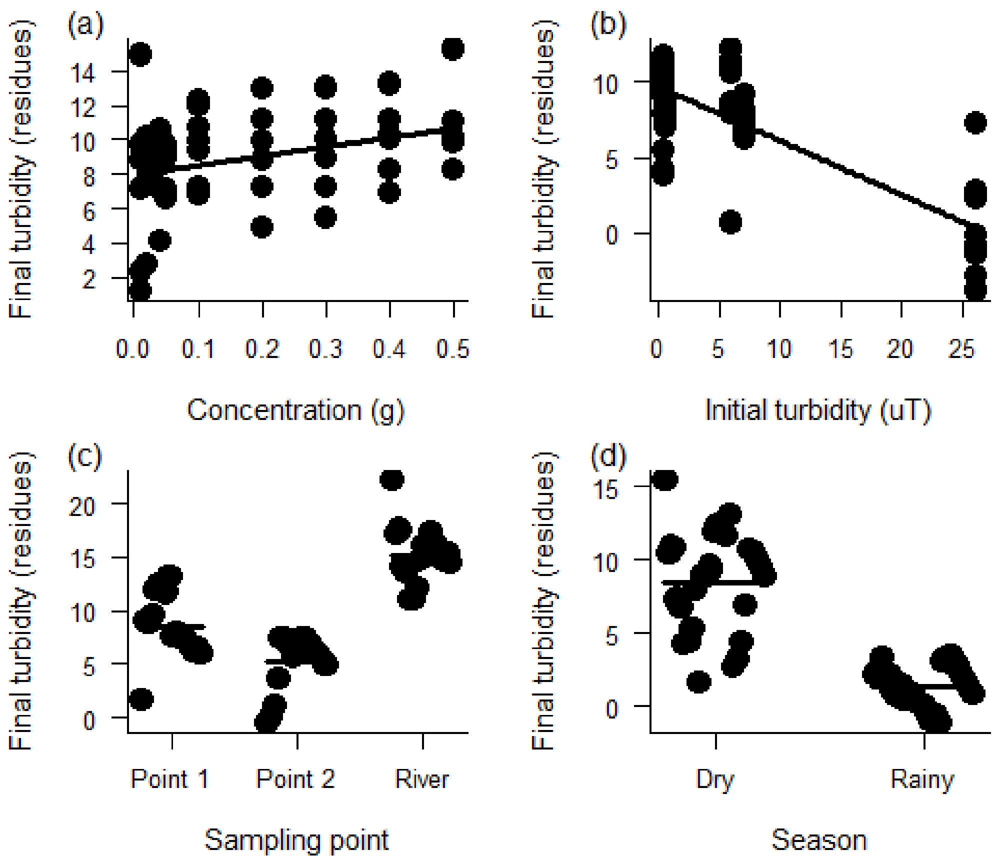
Choy et al. (2014) attribute the increase in organic matter to the presence of lipids, which are biomolecules that do not participate in the coagulation process. Although it was not possible to perform organic matter quantification tests, this effect can be observed in the initial turbidity of 26.17 uT of the water from the Branco River. This used the highest coagulant dosage of 0.5 g of the cactus powder and presented the lowest removal efficiency and left the water with a greenish appearance. However, it is possible to improve the quality of treated water using filters, since the flakes formed by the biomolecules are usually large and easily retained, and do not require more advanced filtration systems (PICHLER et al., 2012).

Figure 3 presents the results of the parameter turbidity after the application of the natural coagulant in the water samples collected in the community of Santa Maria do Boiaçu. Branco, Roraima. The action of the natural coagulant in the removal of turbidity of water from the different points and collection season is evidenced in Figure 3b, when comparing the initial turbidity and the final turbidity, corroborating the results of Karanja et al. (2017) who obtained a satisfactory reduction between the initial and final turbidity when using *Opuntia ficus-indica* mucilage. Such results led the researchers to infer that cactus mucilage is efficient as a natural agent for water treatment.

Unlike some studies that have shown that the higher the turbidity of the water to be treated, the better the efficiency of natural coagulants, the effect observed in the present study was satisfactory (Figure 3c) for samples of surface and groundwater with low turbidity (Table 2). Pritchard et al. (2010) used a natural coagulant based on *Moringa oleifera* seed in the treatment of water with a turbidity of 40 uT and 200 uT, and the removal efficiencies at the end of the treatment were 50% and 90% respectively. Nishi et al. (2011) observed that there was a better removal efficiency in water samples with a turbidity of 350 and 450 uT. A possible justification for this behavior lies in the fact that both *M. oleifera* and cacti are considered polyelectrolytes, in other words, they are flocculating polymers with different ionic charges that act on the formation of flakes and assist in coagulation.

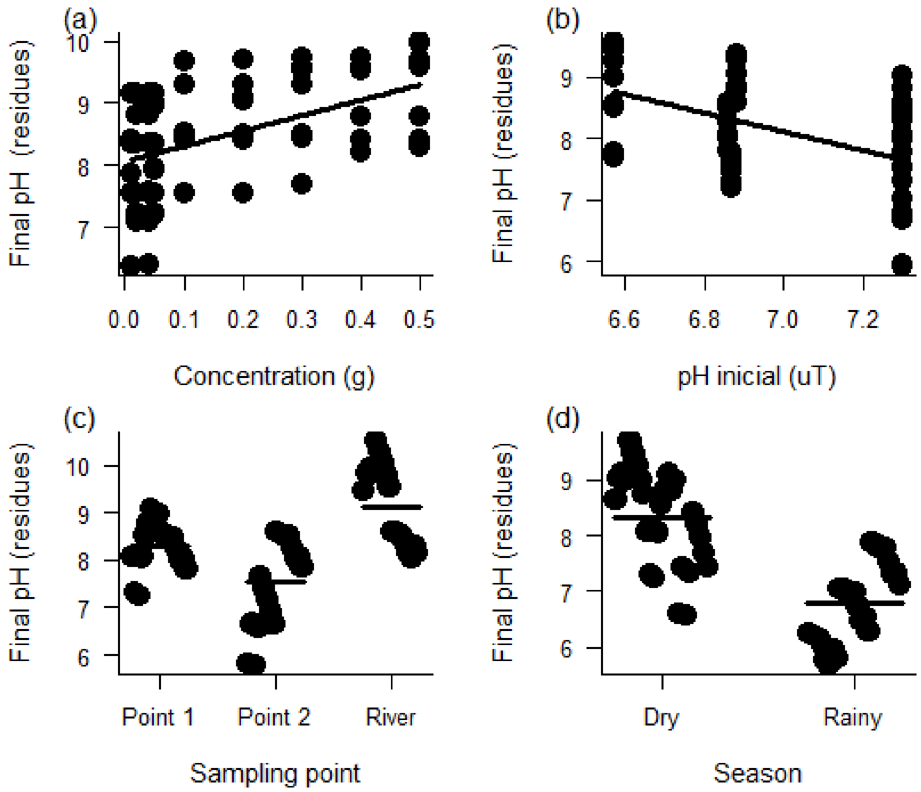
For Baghvand et al. (2010), low turbidity waters have a small amount of colloidal matter, i.e., this lower concentration of suspended colloids in the water limits the contact rate between the particles and the flocculating polymers, thus hindering the coagulation process and, consequently, the performance of the coagulant. An alternative to treating low turbidity waters consists in adding synthetic turbidity to provide the formation of heavier flakes, which makes them more likely to settle. In the present study, no addition of synthetic turbidity was required. The crude water samples collected in the rainy season presented the lowest initial turbidity values (7.18 uT, 0.67 uT and 0.41 uT), when compared to the dry season (26.17 uT, 5.99 uT and 0.39 uT) for the Branco River, Point 1 and Point 2, respectively; and, after the coagulation test, the turbidity levels remained the lowest, as shown in Figure 3d.

Figure 3 - Results of the turbidity parameter after the application of the natural coagulant in the water samples collected in the community of Santa Maria do Boiaçu, Roraima.



The study by Beyene, Hailegebrial and Dirersa (2016) makes a comparison between cactus powder and aluminum sulfate, and reveals that cactus powder is more efficient in maintaining pH. In the present study, there was no comparison between the natural coagulant and the chemical coagulant, and all samples collected had the pH within the expected limit of 6-9. What can be observed is that as the dose of the natural coagulant increased, the pH also increased (Figure 4a); and the doses of coagulant used maintained the pH levels within the desirable limits (Figure 4b). The lowest pH values with the application of the natural coagulant were maintained at Point 2 (Figure 4c). In the rainy season, the lowest pH values were obtained when compared to the dry season (Figure 4d). Karanja et al. (2017) emphasize the importance of studies that present efficacy levels and optimal pH conditions when using cacti as a coagulant. In studies using *Opuntia* cactus powder, the authors found no significant effects for the pH parameter.

Figure 4 - Results of the pH parameter after the application of the natural coagulant in the water samples collected in the community of Santa Maria do Boiaçu. Branco, Roraima.



Conclusion

The social technology produced together with the riverine community of Santa Maria do Boiaçu demonstrated effectiveness in coagulation through the analysis of turbidity and pH parameters, thus allowing their consumption. Replacing polluting chemicals with natural coagulants in the treatment of water for human consumption will contribute to quality of life, and enables any community in a vulnerable condition to produce the natural coagulant and obtain quality water, in addition to protecting the environment and contemplating two important sustainable development goals proposed by the United Nations - health and well-being and drinking water and sanitation. Therefore, it is possible to suggest the execution of new works that seek to perform other tests of physicochemical parameters, coliforms, characterization of natural coagulants obtained from Amazonian cacti, and toxicity and oxidation tests in order to ensure an effective application of cactus coagulants in the treatment of water for human consumption.

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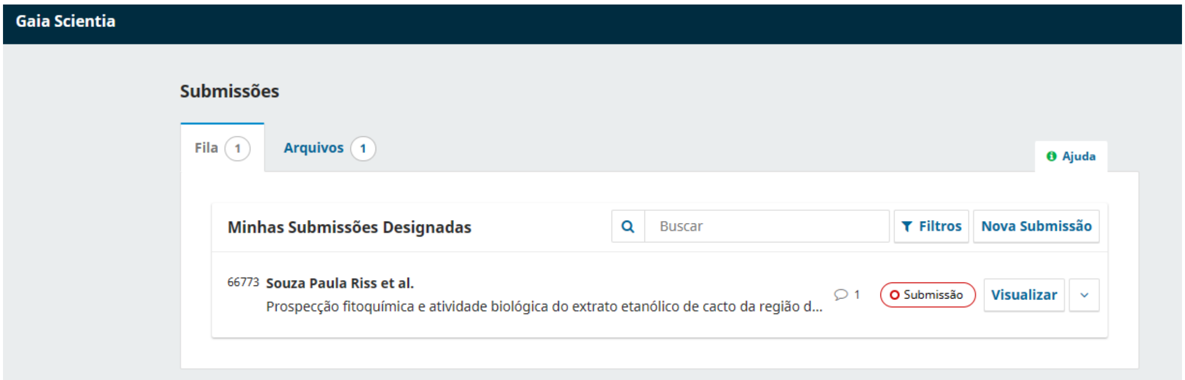
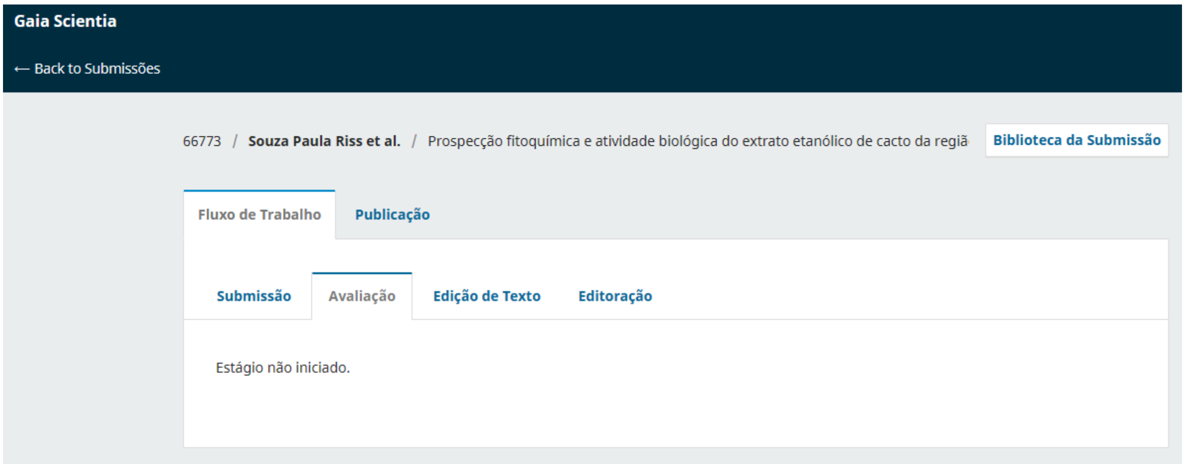




Prospecção fitoquímica e atividade biológica do extrato etanólico de cacto da região do lavrado de Roraima, Brasil

Jordana Souza Paula Riss, Leovergildo Rodrigues Farias, Neyla Raquel dos Santos Rodrigues, Rajá Vidya Moreira dos Santos, Ana Paula Folmer Correa, Marcos José Salgado Vital

Resumo

Lavrado é uma terminologia local dada à região das savanas de Roraima que tem uma elevada importância para a conservação da biodiversidade e dos recursos hídricos. É composto por vegetações de pequeno, médio e grande porte que permeiam lagos e igarapés, em grande parte ladeados por veredas de buritizais (*Mauritia flexuosa*) e com ocorrência de cactos Mandacaru (*Cereus jamacaru* De Candolle). Este trabalho consistiu na prospecção fitoquímica e atividades biológicas do extrato etanólico do *C. jamacaru* coletado no lavrado de Roraima. O extrato foi avaliado quanto à capacidade antioxidante, determinada pelos métodos de DPPH e ABTS, e quanto ao teor de compostos fenólicos totais. O perfil químico foi analisado pelo método APCI-MS. A toxicidade foi avaliada a partir da análise de CL50 em ensaio agudo com *Artemia salina* L. Na prospecção fitoquímica obteve-se a presença dos metabolites secundários: fenóis, taninos, alcalóides, flavonóides, sesquiterpenolactonas e outras lactonas, saponinas, esteróides, triterpenóides, flavonas, flavonóis, flavonas, chalconas, auronas e isoflavonas. A avaliação da capacidade antioxidante foi de 63,8% para o DPPH e de 92,3% nas análises de ABTS. Os valores de compostos fenólicos totais foram 102,4 mg EAG.100 g $^{-1}$.O extrato etanólico não apresentou letalidade frente A. salina nas concentrações de 2250, 2000, 1500, 1250, 1000, 500, 250 e 125 µg.mL $^{-1}$. A atividade antimicrobiana não apresentou inibição nos microrganismos testados em concentrações de até 1 mg/mL.

Palavras-chave: Fitoquímica, Atividade antioxidante, Toxicidade, Atividade antibacteriana, Mandacaru.

Prospección fitoquímica y actividad biológica del extracto etanol de cactus de la región de lavrado de Roraima, Brasil

Resumen

Lavrado es una terminología local dada a la región de sabanas de Roraima que tiene de gran importancia para la conservación de la biodiversidad y los recursos hídricos. Y compuesta por vegetación pequeña, mediana y grande que impregna lagos y arroyos, en gran parte flanqueada por caminos de buritizais (*Mauritia flexuosa*) y con la aparición de Cactus Mandacaru (*Cereus jamacaru* De Candolle). Este trabajo consistió en la prospección fitoquímica y actividades biológicas del extracto etanólico de *C. jamacaru* colectado en el lavrado de Roraima. El extracto fue evaluado por su capacidad antioxidante, determinada por los métodos DPPH y ABTS, y por el contenido de compuestos fenólicos totales. El perfil químico se analizó por el método APCI-MS. La toxicidad se evaluó a partir del análisis CL50 en un ensayo agudo con *Artemia salina* L. En la prospección fitoquímica se obtuvo la presencia de metabolitos secundarios: fenoles, taninos, alcaloides, flavonoides, sesquiterpenolactonas y otras lactonas, saponinas, esteroides, triterpenoides, flavonas, flavonoles, flavonas, chalconas, auronas e isoflavonas. La valoración de la capacidad antioxidante fue del 63,8% para DPPH y del 92,3% en los análisis ABTS. Los valores de compuestos fenólicos totales fueron de 102.4 mg EAG.100 g^{-1} El extracto etanólico no mostró letalidad contra A. salina a las concentraciones de 2250, 2000, 1500, 1250, 1000, 500, 250 y 125 $\mu g.mL^{-1}$. La actividad antimicrobiana no mostró inhibición en los microorganismos ensayados a concentraciones de hasta 1 mg/mL.

Palabras clave: Fitoquímica, Actividad antioxidante, Toxicidad, Actividad antibacteriana, Mandacaru.

Phytochemical prospecting and biological activity of the ethanolic extract of cacti from the "lavrado" region of Roraima, Brazil

Abstract

Lavrado is a local terminology for the savanna and steppic savanna region of Roraima that has a high importance for the conservation of biodiversity and water resources. It is composed of small, medium and large-sized vegetation that permeates lakes and streams, which are largely flanked by rows of buriti palms (*Mauritia flexuosa*), as well as the occurrence of mandacaru cacti (*Cereus jamacaru* De Candolle). This work consists of the phytochemical prospection and biological activities of the ethanolic extract of *C. jamacaru* collected in the lavrado region of Roraima. The extract was evaluated for its antioxidant capacity, which was determined using DPPH and ABTS methods, and for its total phenolic compounds. The chemical profile was analyzed using the APCI-

MS method, and toxicity was evaluated via the LC_{50} analysis in an acute toxicity assay using *Artemia salina* L. In the phytochemical prospection, the presence of the following secondary metabolites was observed: phenols, tannins, alkaloids, flavonoids, sesquiterpene lactones and other lactones, saponins, steroids, triterpenoids, flavones, flavonols, chalcones, aurones and isoflavones. The evaluation of antioxidant capacity was 63.8% in the DPPH and 92.3% in ABTS analyses. The values of total phenolic compounds were 102.4 mg GAE.100 g^{-1}. The ethanolic extract did not present lethality against *A. salina* in the concentrations of 2,250, 2,000, 1,500, 1,250, 1,000, 500, 250 and 125 µg.mL^{-1}. The antimicrobial activity showed no inhibition in the microorganisms tested at concentrations up to 1 mg/mL.

Keywords: Phytochemistry, Antioxidant activity, Toxicity, Antibacterial activity, Mandacaru.

Introduction

Cacti are succulent dicotyledons of a wide range of shapes and sizes, they can be trees, shrubs, vines, epiphytes or geophytes. Stems (stalks) can be columnar, plump, globular, tuberculate, rib-shaped, winged or flattened, though they are usually segmented without leaves and have thorns (Barthlott and Hunt 1993).

In the Americas, cacti are found from the coastal plains to mountains with an altitude of about 3,000 m. Of the four areas identified as centers of cactus diversity, Brazil ranks third in this ranking. It is very common to associate the occurrence of cacti with places of extreme droughts; however, certain cacti inhabit other environments, for example, the shady and humid forests of the Amazon and the Atlantic Forest. Cacti are present in all major Brazilian biomes: Amazon, Caatinga, Cerrado, Atlantic Forest, Pampas and Pantanal (Zappi and Taylor 2020).

The state of Roraima is located in the northwest of the northern region of Brazil, with a predominance of the Amazon Rainforest; however, there is also a huge strip of “lavrado” in the central-eastern part (Barbosa and Campos 2011). The mandacaru (*Cereus jamacaru*) is a cactus that is native to Brazil and can reach up to 10 meters high. It has a woody trunk of about 60 cm in diameter, and many erect stems that form a compact top (Zara et al. 2012). It is abundant in the northeastern region of Brazil (Zara et al. 2012), but is also found in the “lavrado” of Roraima (Oliveira 2016; Passos 2019).

C. jamacaru has as its main phytochemical components two amines (tyramine and N-methyltyramine), in addition to the presence of hordenine and tyrosine. In its cladodes, there is the presence of flavonoids, tannins, anthraquinone saponins and often ß-sitosterol (Da Silva et al. 2017). This diversity of the metabolites, which have pharmacological activity, justifies their use as anti-inflammatory, antibacterial, sympathomimetic drugs and they also have a possible karyotonic activity (Davet et al. 2009; Necchi et al. 2012).

Cacti of the genera *Opuntia* and *Latifaria* are the most studied for the treatment of water, but these studies are considered recent when compared with other natural coagulants such as *Moringa oleifera* (Yin 2010). Natural coagulants, derived from cacti, have also become an alternative for the removal of organic contaminants in waters, since they are a natural, abundant, biodegradable and low-cost biomaterial (Rebah 2017).

Thus, this study consists of the phytochemical screening of the ethanolic extract of *C. jamacaru* collected in the "lavrado", in terms of its antioxidant capacity, its toxicity and antimicrobial activity, with the aim of using the powder of this cactus as a natural coagulant in the treatment of water for human consumption.

Materials and methods

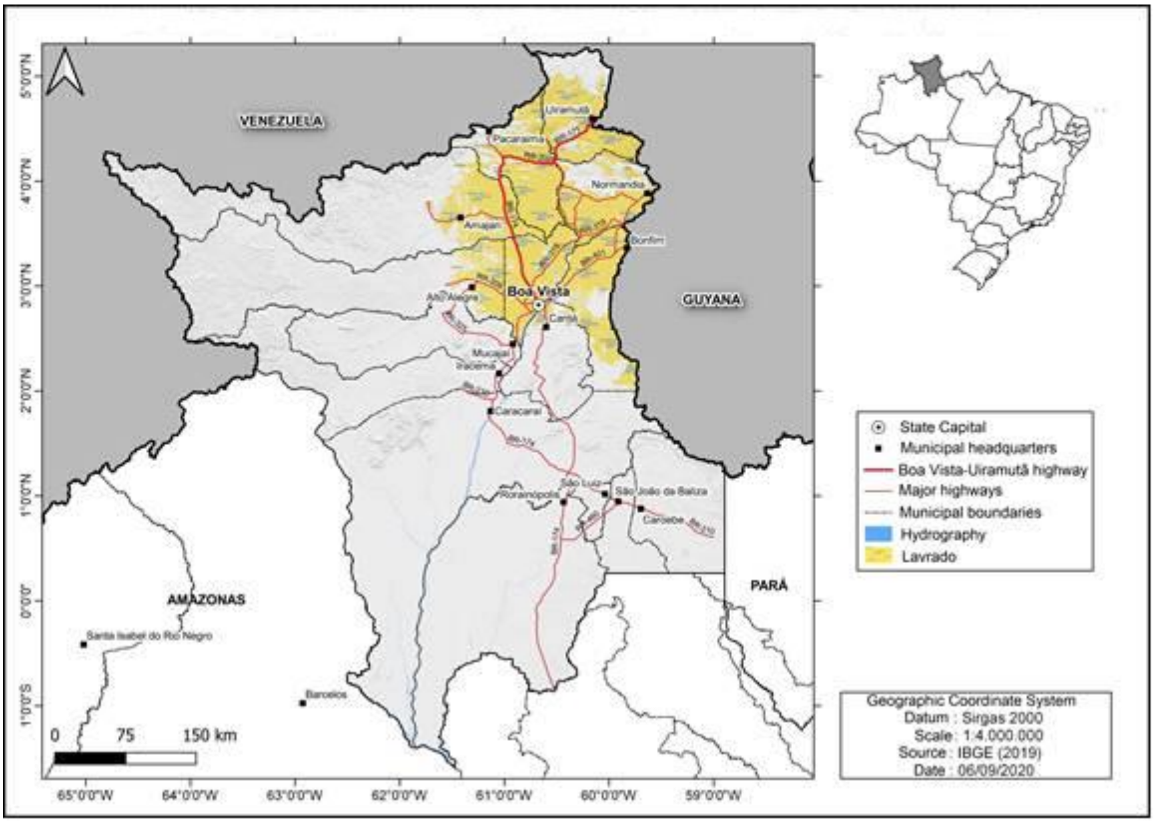
This study was developed in the laboratories of the Graduate Program in Natural Resources (PRONAT) of the Federal University of Roraima.

Description of the area of cactus collection

Comprising an area of 230,104 km^2, the "lavrado" in Roraima borders Guyana and a part of Venezuela (Figure 1), with altitudes ranging between 400 and 800 meters in an extensive mountainous area of Precambrian origin (Miranda and Absy 2000).

For the present study, cacti were collected in the "lavrado" on the verges of the BR 174, RR-202 and RR-171 highways between Boa Vista nd Uiramutã (Figure 1). Prior to the collection stage, a mapping of the occurrence of cacti in the studied area was carried out with the help of GPS equipment (Garmin, etrex 20). Such mapping was a primary factor in determining the species of cactus to be studied.

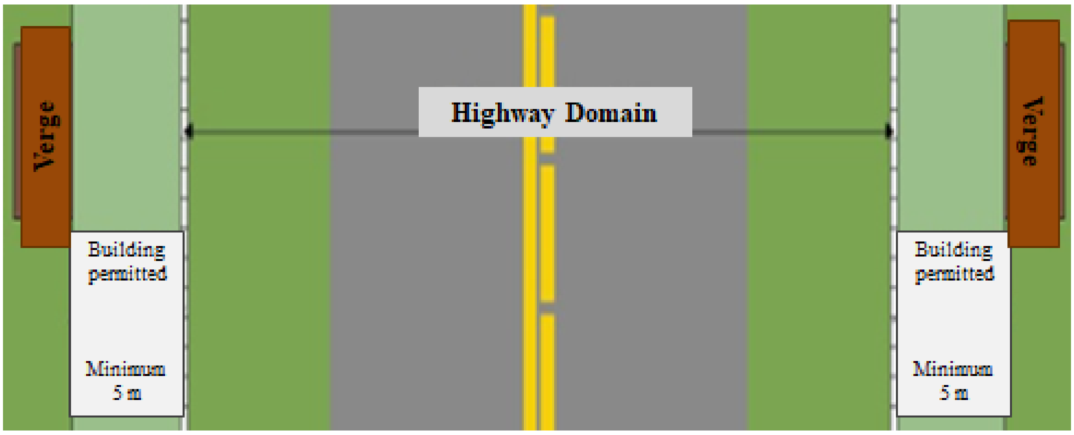
Figure 1. Map of the spatial distribution of the "lavrado" of Roraima and the Boa Vista-Uiramutã highway where the collections of cacti were carried out.



Source: Author

Considering that the path of the study runs through indigenous lands that require authorization for collection, it was decided to map the occurrence of cacti in the public domain, respecting the minimum limit of the verges of the highways. According to Resolution N°. 9, of August 12, 2020, the domain of the highway is the physical basis on which a highway is based, which consists of the roadway, verges, hard shoulders, signage and the safety lanes. The limits are defined by an executive highway project, public utility decrees or expropriation projects. The verge, on the other hand, refers to the area along the public domain lanes of highways (Brasil 2020). The minimum limit of this strip is at least five meters according to Brazilian Law No. 13913/2019 (Brasil 2019) (Figure 2).

Figure 2. Illustrative scheme of the domain of highways and verges where the cacti were collected.



Source: Adapted from Empresa Gaúcha de Rodovias (2019).

Preparation of the extract

For the study, about 1,200 g of the aerial part of *Cereus jamacaru* was used. Thorns from plant material were removed with a knife, then the cladodes were washed under running water, cut, and placed on trays. The pieces were dried in an air circulation oven at 37 ºC for 3 days, and then ground to a powder and stored in a dark and hermetically sealed container. The ethanolic extract of the cladodes of the cactus was prepared using the maceration method. A total of 320 g of powdered cactus was added to 3.0 liters of absolute ethyl alcohol, and left for 7 days. After this period, the extract was filtered through analytical filter paper and concentrated under reduced pressure in a rotary evaporator. Then, the obtained extract was stored and conserved until the completion of the analyses (Martins et al. 2022).

Analysis of the chemical profile using high-resolution mass spectrometry with atmospheric pressure chemical ionization (APCI-MS)

The ethanolic extract of *C. jamacaru* was solubilized in HPLC-grade methanol to generate a stock solution of 1,000 ppm. Aliquots (10 µL) of this solution were transferred to vials containing 1 mL of methanol. Then, 5 µL of the diluted solutions were analyzed by direct insertion in the trap ion mass spectrometer (LCQ Fleet), which was equipped with an APCI source operating in positive and negative modes. The analytical parameters used were: discharge current: 5 µA; vaporizer temperature: 320 ºC; capillary temperature: 220 ºC; sheath gas: 30 psi; aux gas: 10 Arb, mass range, m/z 100-1000. MS/MS spectra were acquired using helium as the collision gas and energy ranging between 20-30%.

Qualitative classification of secondary metabolites

Phytochemical prospection was performed by adapting the methodology proposed by Barbosa et al. (2004). The ethanolic extract was tested for phenols, tannins, phenolic substances, flavones, flavonols, chalcones, isoflavones, saponins, free steroids, free pentacyclic triterpenoids and alkaloids.

Sequestering activity of 2,2-diphenyl-1 picrylhydrazyl radical (DPPH)

The antioxidant activity of the *C. jamacaru* extract was determined using the *in vitro* photocolorimetric method performed via free radical scavenging using DPPH (2,2-diphenyl-1-picrylhydrazyl). The samples were prepared by adding 3.9 mL of DPPH solution (60 µM) in 100 µl of extract solutions, which were diluted in methanol at µM/mL concentrations, in triplicate. After the reaction time of 30 minutes, the absorbances of the prepared samples were read on the UV-Vis spectrophotometer with the wavelength adjusted to 515 nm. As a negative control, a mixture of 3.9 mL of DPPH solution and 100 µL of control solution (Trolox) was used. The antioxidant activity of the samples was expressed in IC_{50} (inhibitory concentration), which was defined as the $mg.mL^{-1}$ of sample required to inhibit the formation of DPPH radicals by 50% (Mensor et al. 2001; Sousa et al. 2007).

2,2'-Azino-bis-(3-ethylbenzothiazoline)-6-sulfonic radical (ABTS)

The sequestering activity of the ethanolic extract was determined using the methodology described by Rhee et al. (2001). The ABTS radical solution (ABTS•+) was prepared by reacting 5 mL of ABTS solution (7 mmol L^{-1}) with 88 µL of K_2SO_4 solution (140 mmol L^{-1}) and allowing the mixture to stand in the dark (at room temperature) for 12-16 hours before use. For the assay, the ABTS+ solution was diluted with 5 mmol L^{-1} PBS buffer solution (pH 7.4) to an absorbance of 0.7

(±0.02) at 734 nm. A sample of 10 µL (500 $mg.mL^{-1}$) was mixed with 1 mL of diluted ABTS+ solution and the absorbance (at 734 nm) was measured after 6 min. The percentage decrease in absorbance was calculated compared to that of the controls. The antioxidant activity value of the extract was compared with the BHT control (synthetic antioxidant). The result was also expressed in milligrams of equivalent.

Total phenolic contents

The total phenolic content was determined using the Folin-Ciocalteau method, modified by Roesler et al. (2007), by which an extract was used at a ratio of 1:10 (w/v). The quantification process was minimized to a total volume scale of 1.0 mL. From this solution, 200 µL of the extract were taken, added to 800 µL of distilled water, 1 mL of Folin-Ciocalteau reagent and 2 mL of 20% sodium carbonate. The absorbance (Abs) of the liquid fraction was determined at 760 nm in a spectrophotometer (Biochrom Libra S12). The result was expressed in gallic acid equivalents (mg $GAE.100\ g^{-1}$).

All readings were performed in triplicate and, with the means of the data, the difference in absorbance between the samples and the control was calculated, with the antioxidant activity (AA) percentages determined using Equation (1).

$$\text{Inhibition of activity (\%)} = (1-B)/A \times 100 \qquad (1)$$

Where:

A = Absorbance of control solution.

B = Absorbance of the solution in the presence of the extract.

Toxicity test using *Artemia salina*

In a round-shaped aquarium that served as an incubator, an artificial saline solution (20 g of sea salt per 1.0 L of distilled water) was added and exposed to the light of a 40 W lamp with aeration, and with a pH of between 8 and 9. After 24 hours, the nauplii (10 units) were placed in test tubes containing the extract of *C. jamacaru* dissolved in DMSO (dimethylsulfoxide) 1% and supplemented with 5 mL of artificial seawater. Concentrations of extracts of 2,250, 2,000, 1,500, 1,250, 1,000, 500, 250 and 125 $\mu g.mL^{-1}$ were tested in triplicate. DMSO was used as the positive control, and was prepared in a similar way to the samples. After 24 hours, the number of dead and living nauplii was counted and the percentage of mortality calculated (Meyer et al. 1982).

Determination of antimicrobial activity

Following the Clinical and Laboratory Standards Institute (CLSI, 2009) the determination of antimicrobial activity and minimum inhibitory concentration (MIC) were performed using the disc diffusion method. For the bacteria, standard strains (ATCC) were used, with Gram-positive: *Staphylococcus aureus* (ATCC25923), *Enterococcus faecalis* (ATCC00531), *Bacillus cereus* (ATCC9634) and *Listeria monocytogenes* (ATCC7644), and Gram-negative: *Escherichia coli* (ATCC10536), *Klebsiella pneumoniae* (ATCC700603) and *Enteric salmonella* (ATCC13076). For the evaluation of antifungal activity, a standard strain of the American Type Culture Collection (ATCC), *Candida albicans* (ATCC10231), was used. The microorganisms were cultured and maintained in tryptone soy agar (TSA) and incubated at 37 ºC for 24 hours. The density of the microbial suspension was adjusted to approximately 10^8 CFU/mL by comparing it with the MacFarland scale (Biomerieux, Italy). This suspension was diluted in sterile saline (0.85%) and, subsequently, the microorganisms were made into a carpet, adding sterile filter paper discs (6 mm Ø) with an aliquot of 20 µL of the extract in certain concentrations, ranging from 500 to 100 $\mu g.mL^{-1}$. For the disc diffusion test, halos with a diameter ≥ 6 mm were considered inhibitory. The antimicrobials amoxilin, vancomycin and fluconazole discs were used as the positive control.

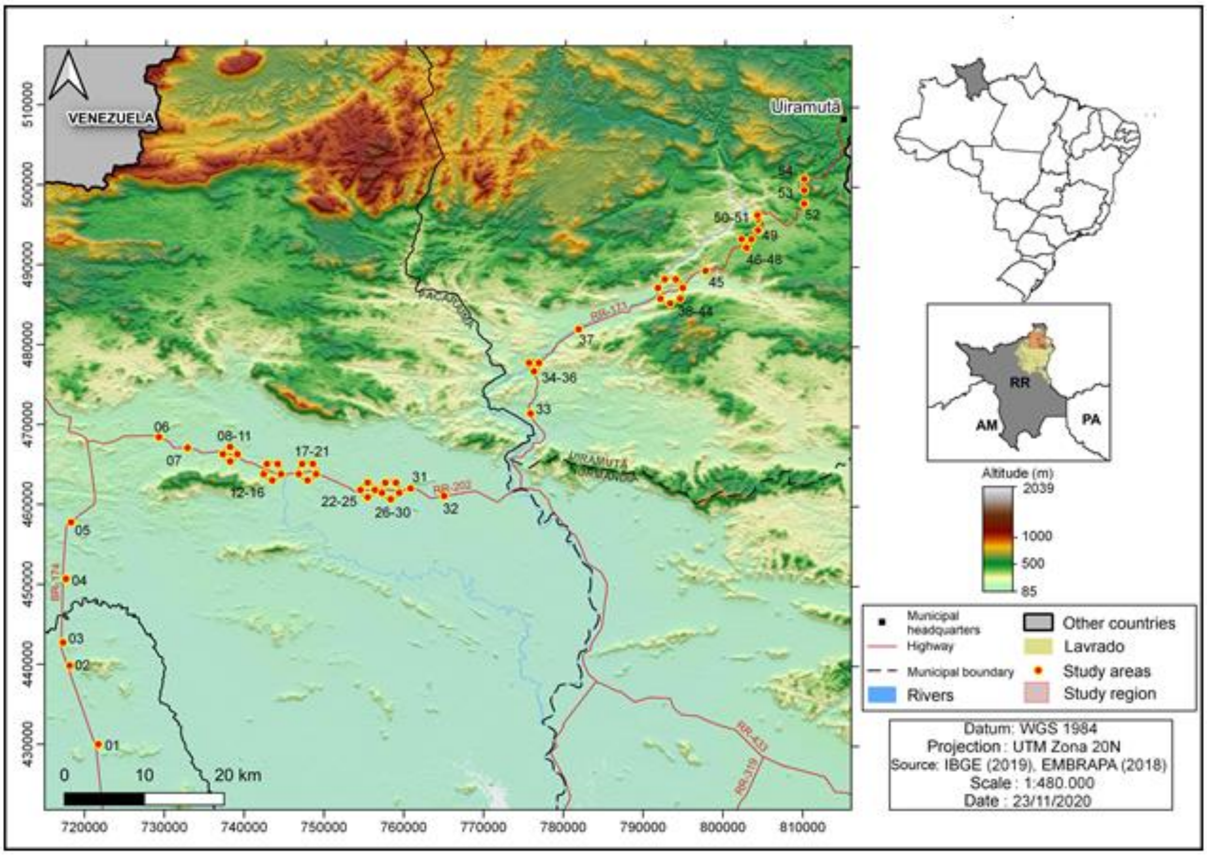
Results and discussion

Below we present the results and discussions regarding the phytochemical prospection, chemical profile and biological activities of the ethanolic extract of *C. jamacaru* from the “lavrado” in Roraima.

Mapping the occurrence of cacti in the lavrado

The occurrences of cacti were recorded along a route of 290 km, within the five-meter limit of the verges, on the BR-174, RR-202 and RR-171 highways, totaling 54 points (Figure 3). The mandacaru (*C. jamacaru*) proved to be the most abundant in this study area, as its occurrence was recorded at all points. Only at point 2 of the route were two other species found, namely *Melocactus neryi* and *Cereus paraensis*.

Figure 3. Location of occurrence points of cacti on the verges of the highway between Boa Vista and Uiramutã, Roraima.



Source: Author

Samples of mandacaru cladodes were collected on the banks of the BR-171 in the municipality of Uiramutã, Roraima, at point 33 of the map at 04°15' 32.01" N 60° 30' 51.12" W. After collection, the plant material was sent to the herbarium at the Federal University of Roraima in order to obtain botanical identification and the ethanol extract in the laboratory.

Extract yield

From 320 grams of powdered cladodes of *C. jamacaru*, we obtained 1,324 grams of ethanolic extract, which is equal to a yield of approximately 0.41%.

Phytochemical prospection

The metabolites found in the crude ethanolic extract of cladodes were phenols, tannins, alkaloids, flavonoids, sesquiterpene lactones saponins, steroids, triterpenoids and flavones (Table 1).

Table 1. Results of phytochemical prospection of the ethanolic extract of cladodes of *C. jamacaru*.

Secondary metabolites	Results	Secondary metabolites	Results
Phenols	+	*Saponins*	+
Tannins	+	*Steroids*	+
Alkaloids	+	*Triterpenoids*	+
Flavonoids	+	*Flavones, flavonols, chalcones, aurones and isoflavones*	+
Sesquiterpene lactones and other lactones	+		

(-) Absence; (+) Presence

The results obtained in the prospection provide information on the chemical classes that make up the extracts. However, it is worth mentioning that there are variations in the profile of secondary metabolites of plant species that have been attributed to biotic and abiotic factors (Hernandez et al. 2022) The presence of tannins and phenolic compounds in the present study corroborate the studies of Dias, Simão, Verib and Carasek (2013) who detected these two substances in the aqueous methanolic extract of the peel of manacaru fruits (*Cereus fernambucenses*), a species belonging to the same family as *C. jamacaru*. The results are also similar to the studies conducted by Felker et al. (2005), Davet et al. (2009) and Medeiros et al. (2019), who detected the presence of tannins, alkaloids, anthraquionones, phenol and flavonoids in the cladodes of *C. jamacaru*.

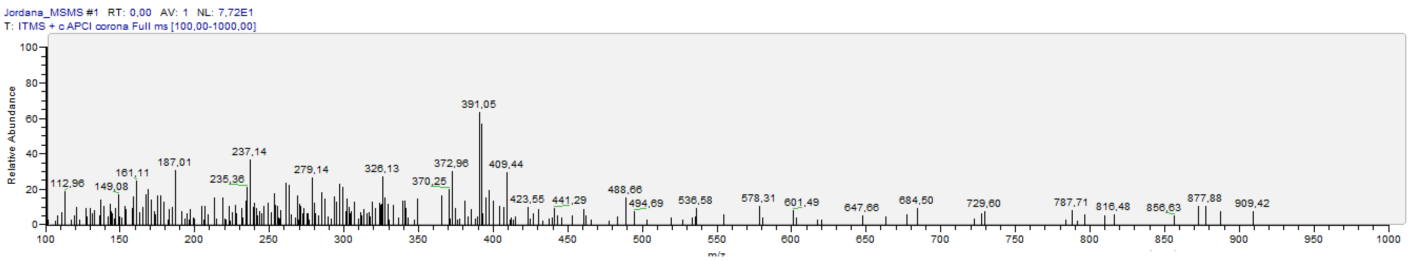
The results of this prospection corroborate the studies of De Almeida et al. (2022), who found the presence of phenols, flavones, flavonols, xanthones and saponins in the ethanolic extract of *C. jamacaru* cladodes. Unlike in the present study, terpenoids were only found in the peel and pulp of ripe and semi-ripe fruits. The authors also detected tannins in their samples.

Phytochemicals such as flavonoids, tannins and alkaloids have anti-inflammatory properties. El-Beltagi et al. (2019) attributed this good antibacterial activity to the tannins present in the cactus *Opuntia ficus-indica*. Alkaloids have been reported to be responsible for antibacterial activity in some plants. This probably explains the reason why plants containing these basic alkaloids and alkaloid salts have good antibacterial properties (El-beltagi et al. 2019).

Chemical profile

The spectrum of the chemical profile of the ethanolic extract of *C. jamacaru* obtained by APCI-MS is represented in Figure 4.

Figure 4. APCI-MS mass spectra of the ethanolic extract of *C. jamacaru*



The possible compounds identified in the positive and negative ionization modes in the fragments are described in Table 2.

Table 2. Compounds identified in the ethanolic extract of *C. jamacaru*

Possible identification	m/z	MS/MS	Reference
Quercetin	301	179; 151	Campelo et al. (2021)
Quecertin hexoside	463	301	Campelo et al. (2021)

Quercetin-3-O-arabinoyl glycoside	595	301	Campelo et al. (2021)
Quercetin di-deoxyhexose	755	446	Campelo et al. (2021)
(Epi) catechin - (Epi) catechin (procyanidin B IV)	577	451; 425; 407; 289; 287	Campelo et al. (2021)
Catechin	289	125; 179; 205; 231; 245	Campelo et al. (2021)
P-coumaric acid	165	119; 147	Campelo et al. (2021)
Caffeic acid	179	135	Campelo et al. (2021)
Ferulic acid	193	134; 149; 178	Campelo et al. (2021)
Apigenin-6-C-glucoside (isovitexin)	431	269; 341	Campelo et al. (2021)
Taxifolin hexoside	435	285; 303; 399	Campelo et al. (2021)
Naringenin hexoside II	433	271; 313; 415	Campelo et al. (2021)
Kaempferol 3-rutinoside-7-rhamnoside	739	593	Campelo et al. (2021)
Kaempferol-3-O-rutinoside	593	285, 255	Campelo et al. (2021)
Benzoic acid derivative	205	143, 125, 81	Campelo et al. (2021)
Benzoic acid derivative	411	205, 143, 125, 81	Campelo et al. (2021)
Benzoic acid derivative	369	205, 125	Campelo et al. (2021)
Saccharide	371	249, 231, 175, 113	Campelo et al. (2021)
Isorhamnetin-3-O-dirhamnosyl glucoside	769	623, 315	Campelo et al. (2021)
Isorhamnetin-3-O-rutinoside	623	315, 300	Campelo et al. (2021)
Oxo-dihydroxy-octadecenoic acid	327	229, 211	Campelo et al. (2021)
L-arginine	175	116	Campelo et al. (2021)
3-O-methylquercetin	317	301; 274; 273	Campelo et al. (2021)
Sucrose	381	201; 219	Campelo et al. (2021)
Apigenin mono-C-glycosidic	433	361; 349; 337; 323	Campelo et al. (2021)
Myricetin-hexose	743	431; 611; 743	Campelo et al. (2021)
D-tyramine	137.2		Schwartz et al. (2010)
N-methyltyramine	151		Schwartz et al. (2010)
Hordenine	165.2		Schwartz et al. (2010)
D-tyrosine	181.2		Schwartz et al. (2010)
Oleic acid	282.4		Schwartz et al. (2010)

Acetic acid	60.1	Schwartz et al. (2010)
Camphor	152.2	Schwartz et al. (2010)
Cysteine	121.2	Schwartz et al. (2010)
Geranylacetone	194	Schwartz et al. (2010)

In the class of flavonols, the presence of quercetin glycosylates, kaempferol, myricetin and isorhamnetin is widely associated with several beneficial health effects, as they present antioxidant, anticancer, anti-inflammatory, antiviral, cardioprotective, and other properties (Wang et al. 2018). Phenolic acids, among them caffeic acid, ρ-coumaric acid and ferulic acid, stand out for being some of the most studied phenolic compounds in cactus species due to their antioxidant action and potential to prevent or delay the appearance of symptoms of transmissible diseases (Del Socorro and Camarena 2019).

The main compounds that are produced by cacti and which have nutritional or pharmacological properties are polyphenols, alkaloids, betalains, terpenes and fatty acids (DAS et al. 2020). Hordenine, N-methyltyramine and tyrosine are some of the most commonly detected alkaloids in cacti. According to Vencioneck Dutra et al. (2018), the alkaloids tyramine and N-methyltyramine are compounds produced by *C. jamacaru* that are chemical markers of this species. Such compounds were identified in the present study with an m/z of 137.2 and 151, respectively.

Oleic acid is known for its beneficial health effects, and is an unsaturated fatty acid that can prevent cardiovascular disease (Bakari et al. 2017). Vitamins can be found in both the pulp and skin of cacti (El-beltagi et al. 2019). Previous studies have indicated that there is a higher concentration of vitamin C (ascorbic acid) in the fruit of cacti (*Opuntia ficus-indica*) than that found in common fruits such as apple, banana or grape. Vitamin C is an important antioxidant and reduces the adverse effects of reactive oxygen species that cause damage to macromolecules, such as lipids, DNA and proteins, which are related to cardiovascular disease, cancer and neurodegenerative diseases.

Antioxidant activity

The values obtained in the radical sequestration methods (DPPH and ABTS) and total phenolic contents are presented in Table 3.

Table 3 - Antioxidant activity of the ethanolic extract of cladodes of *C. jamacaru.*

	Phenolic Compounds Total (mg GAE.100 g^{1}).	**DPPH Radical IC_{50} (mg.mL^{-1})**	**ABTS Radical (µMTrolox g^{-1})**
Ethanolic Extract	102.4 ± 0.05	69.8 ± 0.2	1.843,4 ± 5,74
Gallic Acid	2,931.04 ± 8.8	-	-
Ascorbic Acid	-	100.2 ± 2.26	1.978,4 ± 7,12
BHT	-	94.5 ± 3.4	1.368,7 ± 4,98

(-) Absence

BHT: butylated hydroxytoluene

DPPH and ABTS assays are methods used to measure the antioxidant's ability to scavenge free radicals, which are the main factor in biological damage caused by stress. In studies conducted by Vencioneck Dutra et al. (2018), the hydroalcoholic extract of *C. jamacaru* was able to inhibit the activity of DPPH radicals by up to 57.36% and ABTS antioxidant activity by up to 65.76% when compared to the standards. The results of the present study were even more satisfactory, the ethanolic extract of the cladodes of *C. jamacaru* showed antioxidant activity of 92.3% for the ABTS method and 63.8% for the DPPH method. El-beltagi et al. (2019) attributed the excellent antioxidizing activity of cactus extract to flavonoids. The authors claim that flavonoids are more efficient antioxidants than vitamins, since phenolic compounds are able to slow down pro-oxidative effects on proteins, DNA and lipids via the generation of stable radicals.

A study conducted with the alkaloid tyramine, a compound detected in the extract of *C. jamacaru*, showed strong sequestering activity in the DPPH assay, as well as reducing power, reaching an 86.34% inhibition of the DPPH radical, which may have contributed to the overall antioxidant activity (Yen and Hsieh 1997). The phenolic levels of the cladodes of *C. jamacaru* were lower than the results obtained by Santos-Zea et al. (2011) who found a minimum of 318.1 mg kg^{-1} and 1 g kg^{-1}, and Medina-Torres et al. (2013) who found 1 g kg^{-1} in the cladodes of Mexican cacti using methanol as an extractive vehicle. De Wit et al. (2019) observed that the total phenolic contents are always higher in the stem and seeds of cacti than in their fruits. In this study, levels of phenolic compounds in the cladodes were 102.4 ± 0.05 mg GAE.100 g^{-1}. A possible explanation for obtaining lower levels is the use of ethanol as an extractive vehicle. Methanol has a higher polarity than ethanol due to its hydrocarbon chain being smaller than that of ethanol.

Determination of antimicrobial activity (AMA)

There was no inhibition of microbial activity with the *C. jamacaru* ethanolic extract at the concentrations tested. Unlike the present study, Davet et al. (2009) demonstrated the antibacterial potential of the ethanolic extract of mandacaru stems against *Streptococcus epidermidis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*. The reason why the extract did not show halo inhibition can be attributed to the concentration tested. Rabe and Staden (1997) relate the absence or slight activity in some extracts to the low concentrations of antibacterial compounds in the extracts.

Leyva-Jimenez et al. (2018) tested the 80% ethanol extract of the peel of the fruit of *C. jamacaru* and the best inhibition halo obtained was of 10 mm and, of the eight bacteria tested, the extract inhibited only three. The authors attributed to the inhibition of microbial growth to the presence of certain flavonoids such as rutin or chrysin. Flavonoids are effective against microbial pathogens, since they are a phenolic hydroxyl compound; as the number of -OH groups increase in the natural structure of the compound, toxicity to microorganisms increases (Bardakci et al. 2019).

Toxicity test

In the toxicity tests, the number of dead nauplii was confirmed by visualization with the aid of a magnifying glass after 24 hours, and it was found that the nauplii still showed movement. The results obtained are expressed in Table 4.

Table 4- Results of toxicity test using *Artemia salina nauplii*

	2250 µg. mL^{1}	**2000 µg. mL^{1}**	**1500 µg. mL^{1}**	**12500 µg. mL^{1}**	**1000 µg. mL^{1}**	**500 µg. mL^{1}**	**250 µg. mL^{1}**	**125 µg. mL^{1}**	**C1**	**C2**
	M	M	M	M	M	M	M	M	M	**M**
S	0	0	0	0	0	0	0	0	0	**0**
D	0	0	0	0	0	0	0	0	0	**0**
T	0	0	0	0	0	0	0	0	0	**0**
X	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

S= Sample**; D=** Duplicate**; T=** Triplicate**; X=** Mean**; M=** Dead**; C=** Control

The toxicity test against *A. salina* was performed with the ethanolic extract. The bioassay was performed in triplicate, and live, dead, or paralyzed nauplii were counted, and then mortality was determined at a concentration between 2,250 µg. mL^{-1} and 125 µg.mL^{-1}. Once the mortality count is determined, toxicity is considered low when the 50% lethal dose (LD_{50}) is greater than 1,000 µg.mL^{-1} and high when the LD_{50} is less than 1,000 µg.mL^{-1} (Meyer et al. 1982). With the determination of the data, it was observed that the ethanolic extract does not present lethality against *A. salina*, as there was no mortality in the lethal dose range.

This result demonstrates that the *C. jamacaru* extract has no toxicity. Unlike the study by Sánchez et al. (2016), who evaluated the toxicity of the extract of *O. ficus-indica*, also a member of the *Cactaceae* family and popularly known as the "prickly pear", and found that a concentration of 100 µg/mL was able to eliminate about 60% of the microcrustaceans.

Conclusions

This research identified compounds belonging to the phenolic, tannin, alkaloids, flavonoids, sesquiterpene lactones, saponins, steroids, triterpenoids and flavones in the ethanolic extract of the cladodes of the cactus *C. jamacaru* cactus from Roraima. Such findings provide substantial evidence that this cactus is a potent source of antioxidant and does not exhibit toxicity. Even without having shown antimicrobial activity, the *C. jamacaru* cactus can be used as a natural coagulant.

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5 CONCLUSÕES

O coagulante natural do cacto *C. jamacaru* do lavrado de Roraima possui ação coagulante para o tratamento da água destinada ao consumo humano, podendo ser utilizado tanto para águas superficiais quanto para subterrâneas, independente da sazonalidade.

A prospecção fitoquímica e atividade biológica realizada com o extrato etanólico de *C. jamacaru* evidenciaram o potencial antioxidante e a ausência de toxicidade, ratificando a sua utilização como uma tecnologia social para o tratamento de água para o consumo humano.

A tecnologia social desenvolvida pode ser replicada, visto que a comunidade de Santa Maria do Boiaçu recebeu capacitação e certificação para a produção do coagulante natural, podendo atuar como multiflicadores da tecnologia.

A tecnologia social produzida com a comunidade ribeirinha de Santa Maria do Boiaçu, a partir do *C. jamacaru*, demonstrou eficácia na coagulação da água, permitindo o seu consumo e possibilitando que outras comunidades em condição de vulnerabilidade possam produzir o coagulante natural e obter água de qualidade. Este fato, além de propiciar qualidade de vida aos moradores, protege o ambiente e contempla dois importantes Objetivos de Desenvolvimento Sustentável proposto pela Organização das Nações Unidas: 3: Saúde e bem-estar e 6: Água potável e saneamento.

Dada à importância socioeducacional desta pesquisa, é possível sugerir a execução de novos trabalhos que busquem analisar o extrato aquoso de modo a garantir uma maior eficácia de aplicação do coagulante natural de cacto no tratamento da água para consumo humano, observando-se as condicionantes ambientais. Faz-se necessário o monitoramento da produção do coagulante e da sua utilização pela comunidade.

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