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Salvinia spp. in the post-treatment of landfill leachate

Mikaelle Maria Alves Garcia https://orcid.org/0000-0001-7350-2464
Undergraduate student at the Institute of Agricultural Sciences, Federal University of Uberlândia, Minas Gerais, Brazil. E-mail: mikaelle.garcia99@gmail.com.
Daiane Gabriela Ribeiro https://orcid.org/0009-0006-0972-5480
Doctorate student in the Postgraduate Program in Chemistry, Federal University of Uberlândia, Minas Gerais, Brazil. E-mail: dgribeiro@ufu.br.
Edmar Isaias de Melo https://orcid.org/0000-0002-8308-8874
Ph.D. degree in Analytical Chemistry from the Federal University of Uberlândia (UFU). Associate Professor at the Institute of Chemistry, Federal University of Uberlândia, Minas Gerais, Brazil. E-mail: emelo@ufu.br.
Roseli Mendonça Dias https://orcid.org/0000-0002-7695-3460
Doctorate in Science from the Federal University of Uberlândia (UFU). Adjunct Professor at Civil Engineering Faculty, Federal University of Uberlândia, Minas Gerais, Brazil. E-mail: rmdias@ufu.br.

Abstract

The study aimed to evaluate the tolerance of the aquatic macrophyte *Salvinia* spp. and quantify the removal of Chemical Oxygen Demand (COD) in the post-treatment of landfill leachate. The leachate was collected at the outlet of the facultative lagoon of the landfill in the municipality of Monte Carmelo (Brazil). The experiment was set up in a greenhouse, in triplicate, using 1.5 L plastic containers for the experimental units. For each experimental unit, 1 L of leachate and four arrangements of young and medium-sized aquatic macrophytes were added, which remained for twenty-one days in the greenhouse. The contact times evaluated were 0, 2, 7, 14 and 21 days. Dilutions of the leachate were evaluated (25%, 50% and 100%) and the "blank test" for control. The samples collected were analyzed to determine COD according to the Standard Methods for the Examination of Water and Wastewater methodology. The phytoremediation technique with *Salvinia* spp. proved to be a promising and efficient in the post-treatment of the leachate treated at the landfill, removing approximately 58% of the COD from the leachate from the 100% Experimental Unit.

Keywords: aquatic macrophytes; leached; phytoremediation.

Salvinia spp. no pós-tratamento de lixiviado de aterro sanitário

Resumo

O estudo objetivou avaliar a tolerância da macrófita aquática *Salvinia* spp. e quantificar a remoção de Demanda Química de Oxigênio (DQO) no pós-tratamento de chorume de aterro sanitário. A coleta do lixiviado ocorreu na saída da lagoa facultativa do aterro sanitário do município de Monte Carmelo/MG. A montagem do experimento foi organizada em casa de vegetação, em triplicata, utilizando recipientes plásticos de 1,5 L para as unidades experimentais. Para cada unidade experimental foi adicionado 1 L de lixiviado e quatro arranjos de macrófitas aquáticas jovens e de porte médio, que permaneceram durante vinte e um dias na casa de vegetação. Os tempos de contato avaliados foram 0, 2, 7, 14 e 21 dias. Foram avaliadas diluições do lixiviado (25%, 50% e 100%) e o "teste do branco" para controle. As amostras coletadas foram analisadas para determinação da DQO de acordo com metodologia do *Standard Methods for the Examination of Water and Wastewater*. A técnica de fitorremediação com *Salvinia* spp. mostrou-se promissora e eficiente no pós-tratamento do lixiviado tratado no aterro sanitário, removendo aproximadamente 58% da DQO do lixiviado da Unidade Experimental 100%.

Palavras-chave: macrófitas aquáticas; lixiviado; fitorremediação.

Salvinia spp. en el post-tratamiento de lixiviados de relleno sanitario

Resumen

El estudio tuvo como objetivo evaluar la tolerancia de la macrófita acuática *Salvinia* spp. y cuantificar la eliminación de la Demanda Química de Oxígeno (DQO) en el post-tratamiento de lixiviados de relleno sanitario. El lixiviado fue recolectado en la salida de la laguna facultativa del relleno sanitario del municipio de Monte Carmelo (Brasil). El experimento se realizó en invernadero, por triplicado, utilizando recipientes plásticos de 1,5 L para las unidades experimentales. Por cada unidad experimental se adicionó 1 L de lixiviado y cuatro arreglos de macrófitos acuáticos jóvenes y de tamaño mediano, los cuales permanecieron veintiún días en invernadero. Los tiempos de contacto evaluados fueron 0, 2, 7, 14 y 21 días. Se evaluaron diluciones del lixiviado (25%, 50% y 100%) y "prueba blanco" para control. La determinación de DQO se produjo según metodología de *Standard Methods for the Examination of Water and Wastewater*. La técnica de fitorremediación por *Salvinia* spp. demostró ser prometedora y eficiente en el post-tratamiento de los lixiviados tratados en el relleno sanitario, removiendo aproximadamente el 58% de la DQO del lixiviado de la Unidad Experimental 100%.

Palabras clave: macrófitos acuáticos; lixiviado; fitorremediación.

1 Introduction

The leachate generated in landfills due to the degradation of waste, if not treated correctly, causes the contamination of groundwater and water courses, causing serious damage to public health and the environment. The implementation of treatment and post-treatment techniques for the leachate prior to its release into the receiving body becomes necessary. The use of constructed wetlands for the treatment of effluents has shown good results. This technique uses plants, most commonly macrophytes that have phytoremediation potential.

The use of phytoremediation through constructed wetlands is a promising alternative because it is easy to implement, has good public acceptance and because it is not an invasive technique and can be applied in situ (Pandey; Bajpai, 2019). It is a technology that uses different plants to remediate contaminated areas, as well as degrade, extract, contain or immobilize contaminants from soil and water (Rock *et al.*, 2000). The most significant feature in phytoremediation is the choice of the appropriate plant (Ali *et al.*, 2020) e the successful application of this technique depends on the interaction of physical, chemical and biological processes between plants and the surrounding environment (Pilon-Smits, 2005).

The use of aquatic macrophytes contributes positively to ecosystem metabolism, nutrient cycling and energy flow (Pompêo, 2017). The introduction of these aquatic plants helps remove pollutants found in landfill leachate. The leachate contains the presence of organic compounds (COD, BOD and Total Organic Carbon), inorganic compounds (heavy metals), ammonia, nutrients, among other compounds (Chávez; Pizarro; Galiano, 2019; Sossou *et al.*, 2024).

Some studies can be cited on the treatment of landfill leachate using phytoremediation by aquatic plants. Mannarino *et al.* (2006) developed experiments with wetlands planted with cattails in the Piraí Landfill (Rio de Janeiro-Brazil), finding COD removal of 41%. Preussler, Mahler and Maranho (2015) evaluated the efficiency of leachate treatment using the aquatic macrophytes *Pistia stratiotes* L. (water lettuce), *Echinochloa polystachya* (Kunth) Hitchc. (creeping river grass), *Eichhornia crassipes* (Mart.) Solms (water hyacinth) and *Alternanthera philoxeroides* (Mart.) Griseb., finding COD removal of 63%. Madera-Parra *et al*. (2015) evaluated the COD in landfill leachate using *Gynerium sagittatum*, *Colocasia esculenta* and *Heliconia psittacorum* and the removal was 66%. Amorim *et al*. (2018) evaluated the post-treatment of leachate from the Curitiba Landfill (Paraná-Brazil) using aquatic macrophytes *Echinochloa polystachya* and *Eichhornia crassipes*, obtaining a system efficiency of 30% for COD. In the study by Perera and Yatawara (2021), the emerging macrophyte *Chrysopogon zizanioides* significantly reduced the COD of partially treated leachate at 0% dilution. Pinedo-Hernández *et al.* (2024) found COD removal efficiency in the wetland treatment with *Canna indica*, reaching approximately 59% over 15 days. In addition to the treatment of landfill leachate, there are studies using aquatic macrophytes for the treatment of domestic wastewater, such as the study by Shafi *et al.* (2024), which compared the phytoremediation potential of *Lemna minor*, *Pistia stratiotes* and *Polygonum hydropiperoides* for the treatment of domestic wastewater and after 14 days of cultivation of macrophytes, COD reduced from 65.28% to 73.61% in all treatments.

Aquatic macrophytes *Pistia stratiotes*, *Eichhornia crassipes* and *Salvinia natans*, considered free and fluctuating species, are recommended for surface water systems (Perera; Yatawara, 2021). *Salvinia molesta* and *Pistia stratiotes* have been widely used for the treatment of agricultural, domestic and industrial wastewater, due to their availability and resilience in a toxic environment (Mustafa; Hayder, 2021b).

The species of aquatic macrophyte used in the present study was *Salvinia* spp. This aquatic macrophyte is common in freshwater, and in favorable conditions it spreads rapidly (Peixoto; Pimenta; Antunes, 2005), being effective in removing environmental contaminants (Sotero *et al*., 2024).

In this context, the present study aimed to evaluate the tolerance of the aquatic macrophyte *Salvinia* spp. and quantify the COD removal in the post-treatment of landfill leachate.

2 Material and methods

To study the use of the aquatic macrophyte *Salvinia* spp. to remove COD from landfill leachate after treatment, treated leachate was collected from the Landfill in the municipality of Monte Carmelo-Minas Gerais-Brazil. The landfill has an anaerobic lagoon followed by a facultative lagoon for treating the leachate.

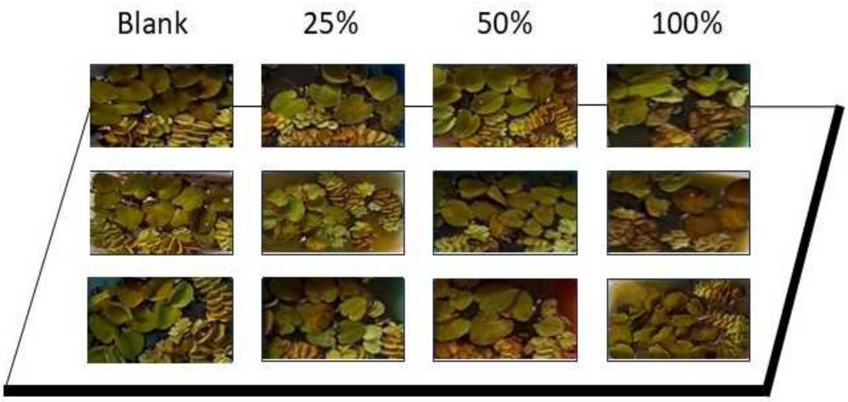
The study consisted of the collection stages and acclimatization period of the aquatic macrophytes *Salvinia* spp.; collection of treated leachate; experiment setup; analytical processes and statistical analysis of data (Table 1).

Table 1. Stages of the study with the aquatic macrophytes *Salvinia* spp.

Stages	Description
Collection and acclimatization period of aquatic macrophytes *Salvinia* spp.	The aquatic macrophytes *Salvinia* spp. were collected in the Mumbuca stream in the municipality of Monte Carmelo (Brazil). The aquatic macrophytes were transported and kept for seven days in a greenhouse for acclimatization, in order to adapt to the lighting and temperature of the place where the experiment was carried out.
Collection of treated leachate	The leachate was collected at the outlet of the facultative lagoon of the Landfill in the municipality of Monte Carmelo (Brazil). The guidelines contained in ABNT NBR 9898:1987 (ABNT, 1987) were followed for the collection of leachate treated by the facultative lagoon.
Experiment setup	The experimental apparatus was organized in a greenhouse, in triplicate, using 1.5 L plastic containers for the experimental units (twelve in total). For each experimental unit, 1 L of leachate and four arrangements of young and medium-sized aquatic macrophytes were added, which remained for twenty-one days in the greenhouse. The contact times evaluated were 0, 2, 7, 14 and 21 days. Dilutions of the leachate were evaluated, being 25%, 50% and 100% (leachate only) and the "blank test" (containing water purified by reverse osmosis to control the tolerance of aquatic macrophytes) (Figure 1).
Analytical processes	The evaluated parameters consisted of chemical oxygen demand (COD) and pH. The liquid samples collected from the experiment were filtered and analyzed. To determine the pH of the samples, the Hanna pH meter (model HI 2221) was used. The DQO was determined according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2017).
Statistical analysis of data	The results were subjected to statistical treatment using the RStudio software (packages, ExpDes.pt and ggplot2). The variables were subjected to analysis of variance (Levene's test, $p < 0.05$) and the Scott-Knott test ($p < 0.05$) (R CORE TEAM, 2023).

Source: Authors (2024)

Figure 1. Representation of the experiment setup with the blank, 25%, 50% and 100% experimental units in triplicate



Source: Authors (2024)

3 Results and discussion

The phytoremediation potential of the aquatic macrophytes *Salvinia* spp. was evaluated in experimental units during a contact time of 21 days, analyzing the parameters pH and chemical oxygen demand (COD) of the leachate treated from the landfill. The leachate treated in the facultative lagoon of the Landfill of Monte Carmelo (Brazil), 100% Experimental Unit, had a pH of 8.80 ± 0.005 and a COD concentration of 1128.67 ± 82.37 mg L^{-1}.

The experimental units were established for 25%, 50% and 100% dilutions, all monitored from the first day (day 0). The pH values on the first day of the experiment were determined in the laboratory, before the experimental units were transported to the greenhouse.

The pH values of the Blank, 25%, 50% and 100% experimental units are presented in Table 2. It is observed that in the Blank Experimental Unit there was a small decrease in pH with seven days of contact time and in the 25% Experimental Unit the pH remained constant. In the 50% and 100% experimental units, there was a slight increase in pH after seven days of contact time.

Table 2. pH in experimental units during 21 days of contact time

Dilutions	pH				
	0 (day)	2 (days)	7 (days)	14 (days)	21 (days)
Blank	7.68 ± 0.17	8.16 ± 0.01	7.25 ± 0.03	7.15 ± 0.41	7.39 ± 0.45
25%	8.85 ± 0.03	8.08 ± 0.63	8.82 ± 0.14	8.52 ± 0.14	8.66 ± 0.03
50%	8.84 ± 0.02	8.96 ± 0.15	9.28 ± 0.28	9.17 ± 0.47	9.03 ± 0.11
100%	8.80 ± 0.01	8.88 ± 0.12	9.31 ± 0.21	9.36 ± 0.21	9.45 ± 0.04

Source: Authors (2024)

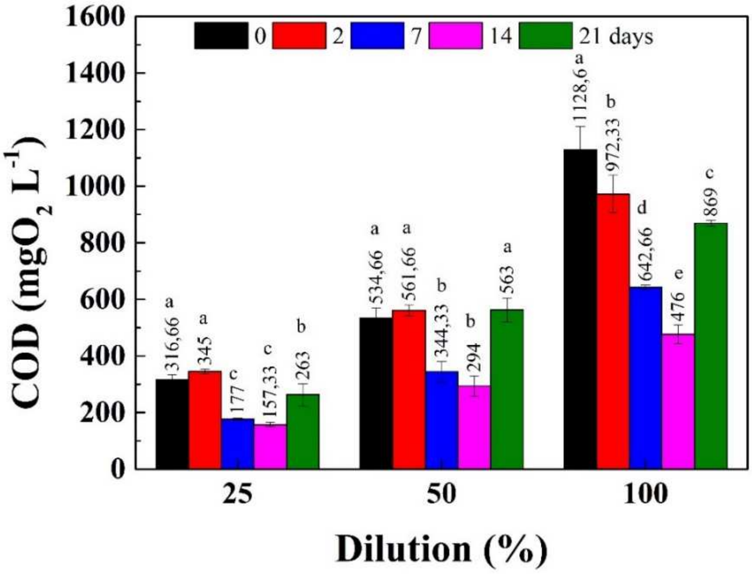
With the removal of CO_2 from the water during photosynthesis, there is a consumption of H^+ ions and an increase in the pH of the water, promoting a relationship between photosynthesis and the pH of the water (Cavalcante; Sá, 2010).

The small changes observed in the pH of the effluent samples in the study by Mustafa and Hayder (2021a) could be attributed to the absorption of contaminants by the aquatic macrophytes *Salvinia molesta*. According to Boyd (1982), the pH rate influences the rapid decomposition of organic matter and nutrients.

The indication of pollution of effluents in water courses can occur through the COD test, which determines the oxygen consumption due to the chemical oxidation of organic matter by a strong oxidant in an acidic environment (Von Sperling, 2017).

The concentrations of COD were determined for the experimental units 25%, 50% and 100% during the 21 days of experiment (Figure 2). With 14 days of contact time between aquatic macrophytes and leachate, the lowest COD concentrations were 157.33 ± 7.64 mg L^{-1}, 294.00 ± 36.06 mg L^{-1} and 476.00 ± 33.15 mg L^{-1}, respectively for the experimental units.

Figure 2. Concentrations of COD for the experimental units 25%, 50% and 100% during 21 days of contact time. Different lowercase letters indicate significant differences from the Scott-Knott test (p < 0.05, n = 3)



Source: Authors (2024)

It can be seen from Figure 2 that the greatest COD removal occurred after 14 days of contact time. For this contact time, the 25% Experimental Unit showed COD removal of 50.31% and the 50% Experimental Unit and 100% Experimental Unit showed COD removal of 45.01% and 57.82%, respectively.

Mustafa and Hayder (2021a) attributed the high COD reduction from their effluent study to the density of the root system of *Salvinia molesta*. Through the rhizodegradation process, macrophytes can reduce COD values (Amorim *et al.*, 2018). In this process, the transfer of oxygen to the rhizosphere, mediated by the roots of macrophytes, increases the aerobic degradation of organic matter (Brix, 1997). The roots of aquatic plants provide a favorable ecosystem for the decomposition of excess nutrients by aerobic microorganisms into organic compounds (Gopal, 1987).

With 21 days of contact time, COD concentrations increased, which may suggest an increase in organic matter in the experimental units from aquatic macrophytes that showed necrosis. At the end of the experiment, some leaves of aquatic macrophytes had increased necrosis. The appearance of necrosis in the leaves was observed in all experimental units from one day of experiment onwards, intensifying until the end of the contact time with the leachate (21 days).

Since leachate has a complex and varied composition, excess sodium can reduce growth, delay germination, and cause toxicity in plants (Matias; Motta Sobrinho, 2020). Zinc toxicity can also cause the development of lesions and necrosis in the leaves of *Salvinia auriculata* (Wolff *et al*., 2009) and reduced plant growth (Fontes; Cox, 1998).

The study by Mota *et al*. (2024) suggested that copper toxicity inhibited the growth of aquatic macrophytes and favored the emergence of necrosis in their leaves when in contact with effluent containing high concentrations of copper. Morphological changes and inhibition of growth of aquatic macrophytes under zinc and cadmium stress were also observed in the study by Li *et al*. (2022).

Ng and Chan (2017) related the cause of the increase in COD to the gradual assimilation of organic carbon from the suspended solids of the palm oil mill effluent linked to plant roots into the water body and the decrease in COD is due to the degradation (oxidation) of the organic carbon into carbon dioxide and water. The authors analyzed the COD to evaluate the water quality of the palm oil mill effluent treated after phytoremediation by the aquatic macrophyte *Salvinia molesta*, obtaining a removal efficiency of 39% at the end of the experiment (16 days).

Tangahu and Putri (2017), in their study on wax removal from industrial wastewater, achieved a COD removal efficiency of 99% in 17 days with *Salvinia molesta*. Alam and Hoque (2018) used *Salvinia cucullata* for wastewater treatment and obtained a removal of 31.04% for COD in a period of 45 days. Laabassi and Boudehane (2019) found 95% COD removal, during 8 days, for the treatment of domestic wastewater using the aquatic macrophyte *Salvinia natans*.

The determination of the wet mass of aquatic macrophytes in the experimental units showed no indication of growth of *Salvinia* spp. during the 21 days of phytoremediation experiment in the post-treatment of landfill leachate. The average wet mass value of the experimental units was 45.50 ± 0.40 g.

As there was no increase in the biomass of *Salvinia* spp. for 21 days, there is no indication of using biomass for other purposes after treating landfill leachate, as occurs in the study by Ng and Chan (2017), which mentions the use of *Salvinia molesta* as compost, fertilizer or mulch for the agricultural sector; in the study by King, Mcintosh and Fitzsimmons (2004), in which *Salvinia molesta* can be used as a food supplement or ingredient in tilapia diets; and in the study by Abbasi; Nipaney and Schaumberg (1990), who demonstrated that *Salvinia molesta* has a higher yield of biogas (methane). The authors obtained an increase in the biomass of *Salvinia molesta*, unlike the result obtained in this study, whose macrophytes showed necrosis in the leaves. It is noteworthy that in the present study, aquatic macrophytes performed a good removal of COD from the leachate, even without developing an increase in wet mass.

4 Conclusion

The aquatic macrophyte *Salvinia* spp. proved to be suitable for polishing the leachate treated by the anaerobic/facultative lagoon system used in the landfill. And it demonstrated its phytoremediation potential by removing COD from the leachate.

To continue the phytoremediation study, it is recommended to include a control group without the presence of aquatic macrophytes, in order to isolate the effect of *Salvinia* spp. and evaluate to what extent COD removal can be attributed to macrophytes in comparison with other natural processes.

The phytoremediation technique using aquatic macrophytes *Salvinia* spp. proved to be efficient and promising in the post-treatment of landfill leachate, removing approximately 58% of the COD from the 100% Experimental Unit leachate (leachate only) for 14 days of contact time.

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