Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Evaluation of the acute phytotoxicity of phototreated textile effluent using cucumber (*Cucumis sativus*) and radish seeds (*Raphanus sativus*)

Avaliação da fitotoxicidade aguda de efluente têxtil fototratado empregando semente de pepino (*Cucumis sativus*) e rabanete (*Raphanus sativus*)

Laís Montenegro Teixeira[1], *Amanda Gondim Cabral Quirino*[1], *Hellen Loyse Sousa Aguiar*[1], *Elisângela Maria Rodrigues Rocha*[1]

ABSTRACT

Water, as a vital resource, plays a crucial role in human activities, notably in the textile industry, whose operations can significantly impact the quality of this resource. It is imperative to explore solutions, such as the adoption of advanced oxidative processes, which encompass the degradation of dyes present in effluents through the action of hydroxyl radicals. To evaluate the effectiveness of this treatment, acute phytotoxicity tests are carried out to analyze the responses of plant organisms to the effluents. Therefore, this study aimed to assess the acute phytotoxicity of a natural textile effluent subjected to heterogeneous photocatalysis and homogeneous photo-fenton treatments. Acute phytotoxicity tests were performed with cucumber (*Cucumis sativus*) and radish (*Raphanus sativus*) seeds, both for the treated effluent and *in natura*. The results revealed a sensitivity of cucumber seeds to effluent *in natura* and resistance to radish seeds. Regarding the phototreated effluents, the results showed an increase in seed germination rate and contributed to enhance this germination. Phytotoxic tests were also carried out with sodium chloride and sodium sulfate, and the toxicity of these substances to cucumber and radish seeds was confirmed.

Keywords: bioindicator; dye; ecotoxicity; photocatalyst.

RESUMO

A água, como recurso vital, desempenha um papel crucial nas atividades humanas, notadamente na indústria têxtil, cujas operações podem impactar significativamente a qualidade desse recurso. É imperativo explorar soluções, como a adoção de processos oxidativos avançados, que englobam a degradação dos corantes presentes nos efluentes por meio da ação dos radicais hidroxila. A fim de avaliar a eficácia desse tratamento, são realizados testes de fitotoxicidade aguda para analisar as respostas de organismos vegetais aos efluentes. Diante disso, este estudo teve como objetivo avaliar a fitotoxicidade aguda de um efluente têxtil real submetido aos tratamentos de fotocatálise heterogênea e foto-fenton homogêneo. Testes de fitotoxicidade aguda foram realizados com sementes de pepino (*Cucumis sativus*) e rabanete (*Raphanus sativus*), tanto para o efluente tratado quanto *in natura*. Os resultados revelaram uma sensibilidade das sementes de pepino ao efluente *in natura* e resistência às sementes de rabanete. Em relação aos efluentes fototratados, os resultados mostraram o aumento da taxa de germinação das sementes e contribuíram para potencializar essa germinação. Também foram realizados testes fitotóxicos com cloreto de sódio e sulfato de sódio, substâncias geralmente utilizadas no processo têxtil, e pôde-se comprovar a toxicidade dessas substâncias nas sementes de pepino e rabanete.

Palavras-chave: bioindicador; corante; ecotoxicidade; fotocatalisador.

[1]Federal University of Paraíba – João Pessoa (PB), Brazil.

Corresponding author: Laís Montenegro Teixeira – Universidade Federal da Paraíba – Campus I – Castelo Branco – CEP: 58051-900 – João Pessoa (PB), Brazil. E-mail: laismontenegrot@gmail.com

Conflicts of interest: the authors declare no conflicts of interest.

Funding: Federal University of Paraíba (UFPB) and Coordination for the Improvement of Higher Education Personnel (CAPES, *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil*), Finance Code 001, and Paraíba State Research Support Foundation (FAPESQ, *Fundação de Apoio à Pesquisa do Estado da Paraíba*) under grant numbers 3147/2021 and 1868/2022.

Received on: 12/07/2023. Accepted on: 06/10/2024.

https://doi.org/10.5327/Z2176-94781861

Introduction

The textile industry in Brazil is characterized by its socio-economic importance, which reached revenues of R$194 billion in 2021, according to the Brazilian Textile and Apparel Industry Association (ABIT, 2022). However, despite its economic importance, in the development of the textile sector, there is high water consumption, especially in the dyeing and finishing stages, generating around 200 L of effluent per kilo of fabric produced daily and discharging effluents containing a high volume of inorganic and organic contaminants into ecosystems (Nidheesh et al., 2022).

Among the inorganic contaminants are heavy metals (mercury, chromium, cadmium, lead, arsenic) necessary for producing fabric pigments, sodium chloride (NaCl), and sodium sulfate (Na_2SO_4), used as electrolytes in the dye bath. These promote the exhaustion of the dye, making it susceptible to approach to hydrogen bonds, aiding its effectiveness in bonding with the fiber (Singha et al., 2021).

The low biodegradability of effluents is generally attributed to the existence of recalcitrant organic products, including dyes, which are widely used in various industrial sectors (Oyeniran et al., 2021) and have proven carcinogenic and mutagenic activities (Li et al., 2020). Industrial processes such as washing, bleaching, and degumming require synthetic dyes (Waghmode et al., 2019).

Organic pollutants also harm plant flowering and germination. Seed germination percentage, seedling height, and survival are the leading indicators of plant growth and health after exposure to textile dyes (Samuchiwal et al., 2021). Growing plants synthesize dry matter, as evidenced by their healthy, green stems. Thus, the higher the concentration of solids containing dyes in industrial effluents, the more detrimental effects occur on plant growth (Zou et al., 2019).

The discharge of effluents into the environment begins mainly in the aquatic system, making it the entry point into the ecosystem (Saravanakumar et al., 2022). Toxic chemicals are transported and the effluent is produced. They remain in the water and soil for long periods, posing severe health risks to living organisms (Dutta and Bhattacharjee, 2022). Therefore, as an alternative for treating textile effluents, advanced oxidative processes (AOPs) have been much studied and commented on in recent years, which are based on highly oxidizing species to promote more effective degradation of the pollutant to be treated.

The principle of AOPs is the generation of hydroxyl radicals (•O.H.), which are responsible for contaminant molecules degradation (Ma et al., 2021). Different processes are used to generate the hydroxyl radical: photolysis (H_2O_2/UV), Fenton (Fe^{+2}/H_2O_2), photo-Fenton ($UV/Fe^{+2}/H_2O_2$), heterogeneous photocatalysis (UV/TiO_2) and ozonolysis (UV/O_3) and electrochemistry. These methods can rapidly remove the dye under adverse conditions (Rahmani et al., 2019).

Even after treatment, the effluent can still present polluting potential and toxicity to ecosystems, thus generating severe environmental impacts. Therefore, phytotoxicity tests can be used to evaluate the response of test organisms to toxic components in the water. Sobrero and Ronco (2004) define phytotoxicity as a static test of acute toxicity, in which the poisonous effects of pure compounds or complex mixtures can be evaluated during seed germination and seedling development during the first days of growth.

Toxicity tests on plant organisms have advantages such as simplicity in carrying out the test, sensitivity to indicating toxic substances, and low cost. However, these analyses are limited in not explicitly identifying the contaminants that cause toxicity (Peduto et al., 2019). Phytotoxicity analysis is the most sensitive and inexpensive method for analyzing wastewater toxicity (Al-Ansari et al., 2022).

This study aimed to evaluate the acute phytotoxicity of natural and phototreated textile effluent, using cucumber (*Curcumin sativus*) and radish (*Raphanus sativus*) seeds as bioindicators. It also analyzed the effects of NaCl and Na_2SO_4 on the germination of these seeds. The results will be fundamental to understanding the potential impact of this treated effluent on the environment and will provide information for the textile industry and environmental regulatory agencies.

Material and Methods

The textile dyeing effluent came from a small weaving industry in Paraíba, in the Industrial District. The quantity collected was 60 L, and the type of treatment previously applied by the industry to this effluent was coagulation/flocculation with the addition of aluminum sulfate, polymer, and decolorizer, followed by decantation (tanks with a capacity of 100,000 L) and filtration (filter made up of brick, gravel, and sand). The sludge from the decanting process was collected after being dried by a specialized company for proper disposal.

The textile effluent collected had a biochemical oxygen demand (COD) of 324.43 mgO_2/L, 542.83 mg Cl/L of chlorides, 2087.00 mg/L of total solids, and a hydrogen potential (pH) of 7.92. The first treatment for this textile effluent (Test 1) was carried out by applying the heterogeneous photocatalysis process, with the electrolytic paste of the zinc- and manganese-based AK battery as the catalyst. The methodology used followed the work of Viana et al. (2023). The second treatment (Test 2) was performed using the homogeneous photo-Fenton process, in accordance with Rocha et al. (2020), with iron sulfate ($FeSO_4$) as the catalyst and hydrogen peroxide (H_2O_2) as the oxidizer.

The natural and treated textile effluent samples were diluted in different percentages, as described in Table 1. All tests were conducted in triplicate at the Environmental Sanitation Laboratory of the Federal University of Paraíba (UFPB), and distilled water was used for the negative control.

Table 1 – Planning of phytotoxicity tests with cucumber and radish seeds.

Test	Total plates (n)	Total seeds of each species (n)	Dilutions (%)
Real textile effluent	36	180	5, 10, 15, 25, and 50
Test 1	42	210	10, 20, 30, 40, 50, and 100
Test 2	42	210	10, 20, 30, 40, 50, and 100

The germination tests were carried out with cucumber and radish seeds, both from the Feltrin brand, adapting the methodologies used by Sobrero and Ronco (2004). Petri dishes (90 mm) were sterilized with sulfuric acid (H_2SO_4) at a concentration of 20% and washed with distilled water. Seeds of ten species were randomly placed in each dish on qualitative filter paper soaked with 6 mL of the liquid sample. The plates were then sealed and incubated in the dark at 22°C, standard deviation (±) 2°C, in a biochemical oxygen demand (BOD) incubator for 120 hours. After this period, they were removed from the incubator, and the roots and stem lengths of the seedlings were measured.

After the results of the phytotoxicity tests, the seeds with the most significant resistance to growth inhibition—the radishes—were analyzed to provide a general measure of the accuracy of the toxicological method. These seeds were used as a positive control with salts of NaCl and Na_2SO_4 since these are substances used in the textile industry in the process of fixing the dye to the fabrics. Their concentrations, shown in Table 2, were based on studies by Cesário (2017) and Moraes Júnior and Bidoia (2015) to obtain the inhibitory concentration of 50% (IC50) of the organisms, calculated through regression analysis of the germination index (GI) data, using Minitab software.

The parameter observed in the acute phytotoxicity tests was the GI, based on the work of Soares et al. (2013). The following percentages are required to obtain the GI: relative seed germination (RSG) and relative root length (RRG). Equation 1 was used to calculate RSG:

$$RSG\ (\%) = \frac{N_{SG,T}}{N_{SG,B}} \times 100 \quad (1)$$

Where:

$N_{SG,T}$: arithmetic mean of the number of seeds germinated in the treatment; and

$N_{SG,B}$: arithmetic mean of the number of seeds germinated in the blank (distilled water).

Equation 2 was applied to determine RRG:

$$RRG\ (\%) = \frac{L_{R,T}}{L_{R,B}} \times 100 \quad (2)$$

Where:

$L_{R,T}$: average root length of the aqueous extract (treatment); and

$L_{R,B}$: average root length of the blank (distilled water).

Finally, the calculated RSG and RRG values were used to stablish the GI values suggested by Zucconi (1981), based on Equation 3:

$$GI = \left(\frac{RSG \times RRG}{100}\right) \quad (3)$$

After generating the data, the values obtained in the phytotoxicity tests were applied to Equations 1, 2, and 3, and the qualitative phytotoxicity classification scale proposed by Soares et al. (2013) was considered, as shown in Table 3.

Table 2 – Positive control concentrations used in the phytotoxicity test.

Positive control	Concentrations (M)
NaCl	0.12; 0.14; 0.16; 0.18; 0.2
Na_2SO_4	0.02; 0.04; 0.06; 0.08; 0.1

M: molar; NaCl: sodium chloride; Na_2SO_4: sodium sulfate.

Table 3 – Germination index classification.

GI (%)	Classification of the material under analysis
>100	The material enhances plant germination and root growth
80–100	Non-phytotoxic, matured compost
60–80	Moderately phytotoxic
30–60	Phytotoxic
<30	Very phytotoxic

Results and Discussion

Real textile effluent

The test using real effluent (with results shown in Table 4) was performed to determine how much it affected seed germination and how sensitive these seeds were.

The control group (CN) showed 100% germination for cucumber and 77% for radish, and the CV remained below 30%, proving the heterogeneous distribution of the data resulting from the diluted textile effluent samples and their harmful effects on seed germination.

It can be seen that the result of the phytotoxicity test with the real effluent diluted in distilled water up to 50% proved to be toxic to cucumber seed germination, which is a warning sign of the possible environmental damage that this effluent can cause when released without adequate and effective treatment. The study by Hoss et al. (2019) shows the excellent sensitivity of cucumber seed in phytotoxicity tests with raw leachate and after treatment by a rotary biological reactor. For the raw leachate, the cucumber germination rate was 49.61%, while for the effluent after treatment, the cucumber seed germination rate was 82.49%.

Radish seed germination was enhanced, showing that it is resistant to the textile effluent analyzed. Engelhardt et al. (2020) observed that radish seeds are more resistant to the toxicity of effluents than other seeds.

Phototreated textile effluent

The GI percentage and its phytotoxic effect were obtained from the phytotoxicity test with cucumber (Table 5) and radish (Table 6) after the treatment process using heterogeneous photocatalysis (Test 1) and photo-Fenton (Test 2).

Table 4 – Results of the real effluent phytotoxicity test on cucumber and radish seeds.

Indexes	Seed	CN	Dilution percentage				
			5	10	15	25	50
ML (cm)	Cucumber	9.15	1.49	2.59	1.94	3.60	2.19
	Radish	12.73	12.49	13.23	15.67	15.68	16.83
CV (%)	Cucumber	18.00	77.00	84.00	90.00	82.00	95.00
	Radish	28.00	31.00	30.00	35.00	41.00	40.00
GI (%)	Cucumber	100	9.21	7.54	12.02	9.18	8.76
	Radish	77.00	106.66	108.44	123.09	128.56	132.22
Effect	Cucumber	-	Very phytotoxic	Very phytotoxic	Very phytotoxic	Very phytotoxic	Very phytotoxic
	Radish	-	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination

ML: medium length; CV: coefficient of variation; GI: germination index; CN: negative control.

Table 5 – Results of the phytotoxicity test of the effluent treated with cucumber seeds.

Indexes		CN	Dilution percentage					
			10	20	30	40	50	100
ML (cm)	Test 1	9.15	6.89	6.34	4.44	7.06	9.39	6.81
	Test 2	9.15	12.22	11.86	10.45	12.31	12.55	11.86
CV (%)	Test 1	18.00	32.00	17.00	29.00	27.00	22.00	25.00
	Test 2	18.00	14.00	14.00	19.00	14.00	13.00	11.00
GI (%)	Test 1	100	30.11	18.46	14.57	12.85	102.61	52.07
	Test 2	100	133.49	125.22	114.12	134.44	137.06	12.22
Effect	Test 1	-	Phytotoxic	Very phytotoxic	Very phytotoxic	Very phytotoxic	Enhanced germination	Phytotoxic
	Test 2	-	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination

ML: medium length; CV: coefficient of variation; GI: germination index; CN: negative control.

Table 6 – Results of the phytotoxicity test of the effluent treated with radish seeds.

Indexes		CN	Dilution percentage					
			10	20	30	40	50	100
ML (cm)	Test 1	12.7	12.65	13.20	12.50	12.63	8.29	8.48
	Test 2	12.7	14.34	12.83	10.62	12.25	11.08	10.33
CV (%)	Test 1	28	31.00	27.00	32.00	28.00	31.00	38.00
	Test 2	28	34.00	36.00	29.00	34.00	24.00	35.00
GI (%)	Test 1	77	99.42	99.25	106.80	99.25	31.16	43.46
	Test 2	77	107.75	100.22	76.22	92.07	83.07	67.03
Effect	Test 1	-	Enhanced germination	Enhanced germination	Enhanced germination	Enhanced germination	Phytotoxic	Phytotoxic
	Test 2	-	Enhanced germination	Enhanced germination	Moderately phytotoxic	Non-phytotoxic	Non-phytotoxic	Moderately phytotoxic

ML: medium length; CV: coefficient of variation; GI: germination index; CN: negative control.

The control group is uniformly developed and presents all the parameters needed to validate the tests. All the coefficients of variation (CV) were below 30% (18% for cucumber and 28% for radish).After treatment in Test 1, the samples had a phytotoxic effect on cucumber seeds, affecting seed germination. However, for radish seeds, it was observed that the dilutions did not show any acute toxicity in the Test 1 samples, only for the effluent with 50% dilution and without dilution (100%). This may have been because the catalyst used in the treatment is manganese-based, which is one of the essential nutrients for plant growth and development, and this compound possibly remained in the effluent after treatment.

For the phytotoxicity tests after Test 2, the growth of the two seeds analyzed was generally enhanced. The effluent treated by the photo-Fenton process did not affect the development of the seeds during the germination process. One reason for this would be the degradation of organic compounds, which are toxic to the environment.

Mohamed et al. (2023) evaluated the phytotoxicity of a synthetic textile effluent with the reactive yellow-145 dye, using tomato seeds (*Lycopersicon esculentum*) as bioindicators. The tests were conducted on the titanium dioxide (TiO_2) photocatalysts produced, the treated dye solution, and the solution containing only the reactive yellow-145 dye (control solution). The seed germination rates were 79, 60, and 30%, respectively.

Dhaouefi et al. (2019) assessed the direct effect of raw and treated wastewater on radish germination. The treatment used an anaerobic/aerobic algae-bacteria photobioreactor to treat the synthetic solution of dispersed orange-3 and blue-1. After incubating the radish seeds in the dark at 25±1°C for a week, the toxicity test results were obtained based on a comparison with a control test (100% seed germination and no inhibition) and indicated that the treated water did not inhibit seed germination. At the same time, the raw effluent caused inhibition of 52±6%. Evaluation of the germination rate revealed 97±1% when irrigated with treated water and only 6±2% when rinsed with raw water.

Figure 1 shows the results obtained from assessing germination. When comparing the images of the negative control using distilled water with the effluent treated without dilution (100% dilution) by Test 2, it is possible to observe that seed germination was potentiated in both species analyzed.

Figure 2 shows the statistical analysis of the cucumber data according to Dunnett's test for natural and treated effluent.

When analyzing the seedling growth data and comparing the averages with the control, it was found that the average length of the seedlings in all dilutions of the real effluent treated by Test 2 differed significantly from the control group, according to Dunnett's test (α=0.05). If an interval does not contain the zero (0) shown in the graph, the corresponding average significantly differs from the control average.

However, according to Dunnett's test, the statistical results for Test 1 show that the seedling lengths in the 10, 40, and 50% dilutions are similar to those of the negative control.

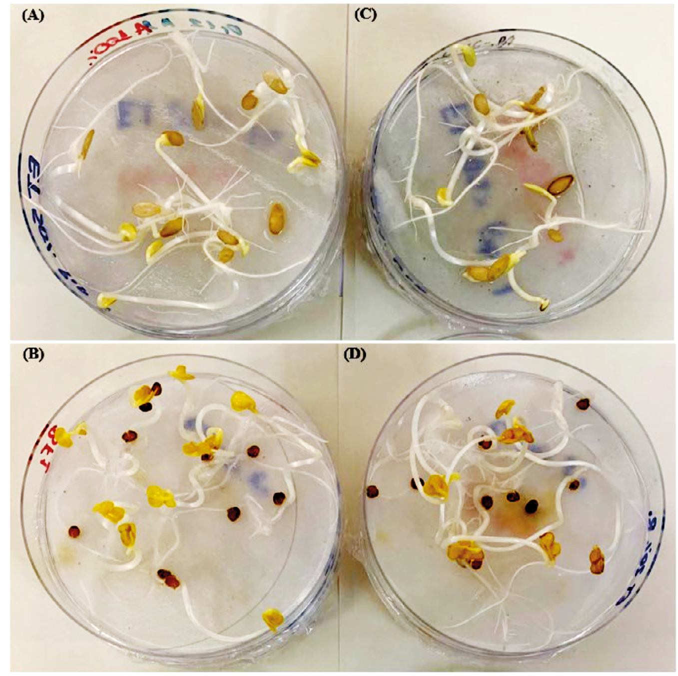

Figure 1 – Germination of seeds from the acute phytotoxicity test with negative control: (A) cucumber, and (B) radish. Germination of seeds from the acute phytotoxicity test without diluting the effluent treated by Test 2: (C) cucumber, and (D) radish.

Figure 3 shows the statistical analysis of the radish data according to Dunnett's test for natural and treated effluent. When comparing the seedling growth averages with the negative control, it was found that the average length in all dilutions of the real effluent treated by Test 2 is significantly similar to the control group, according to Dunnett's test, with 95% significance. If an interval contains zero (0), the corresponding average is significantly similar to the control average.

According to Dunnett's test, the results for Test 1 showed statistical similarity in the dilutions with the negative control. The seedling length results differed from the negative control only at 50% dilution.

Sodium chloride (NaCl) and sodium sulfate (Na_2SO_4)

Table 7 shows the main results of the positive control obtained in the phytotoxicity test of NaCl and Na_2SO_4 at different concentrations for radish seeds only. Good data about the negative control can be observed as the seeds developed considerably, maintaining 30% CV, within the expected range for the radish, thus attesting to the health and quality of the batch of seeds.It can be seen that, for the negative control, the average length of the seedlings was 10.13 cm, while for the dilutions of both positive control reagents tested, the ML became lower and lower (decreasingly). As the concentration of the substances increased, phytotoxicity increased, negatively impacting radish seed germination. This highlights the importance of rigorously monitoring the concentration of these substances in the industry and their effluent.

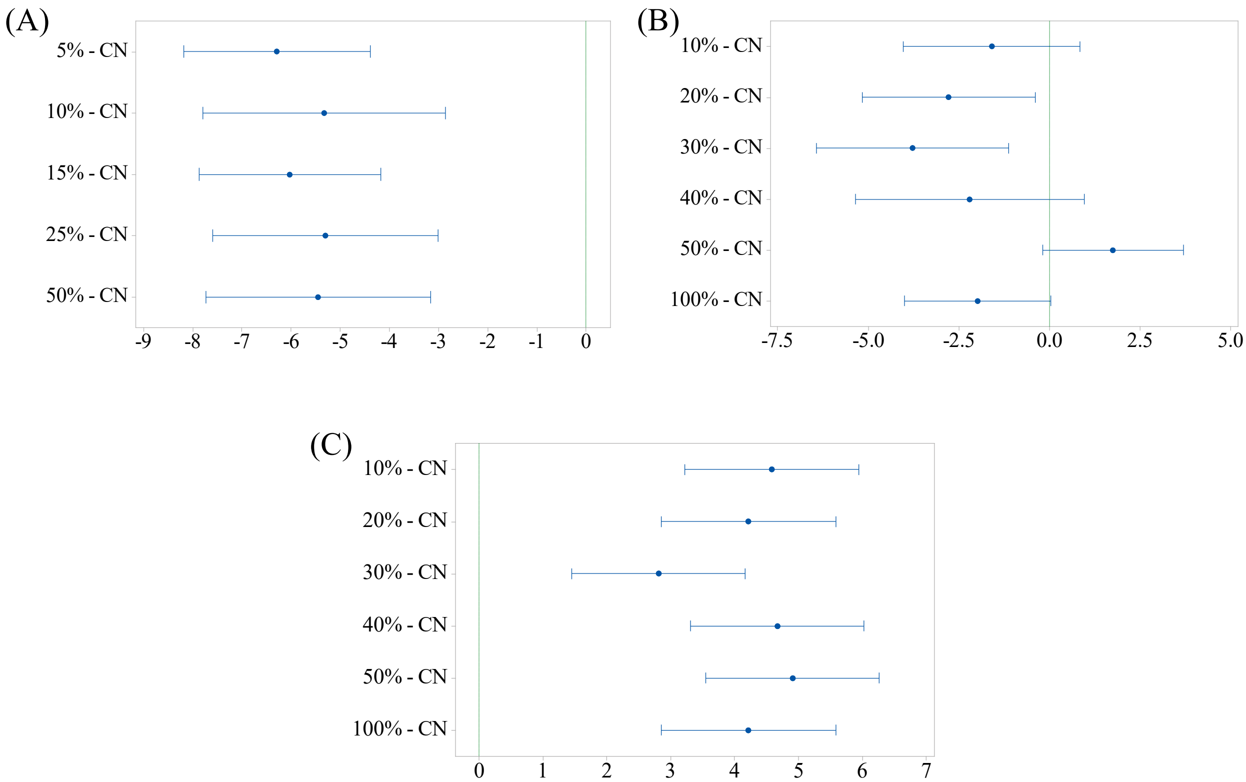

Figure 2 – Dunnett's test results for acute phytotoxicity using cucumber seed as a bioindicator with effluents: (A) Real; (B) Treated by Test 1; and (C) Treated by Test 2.

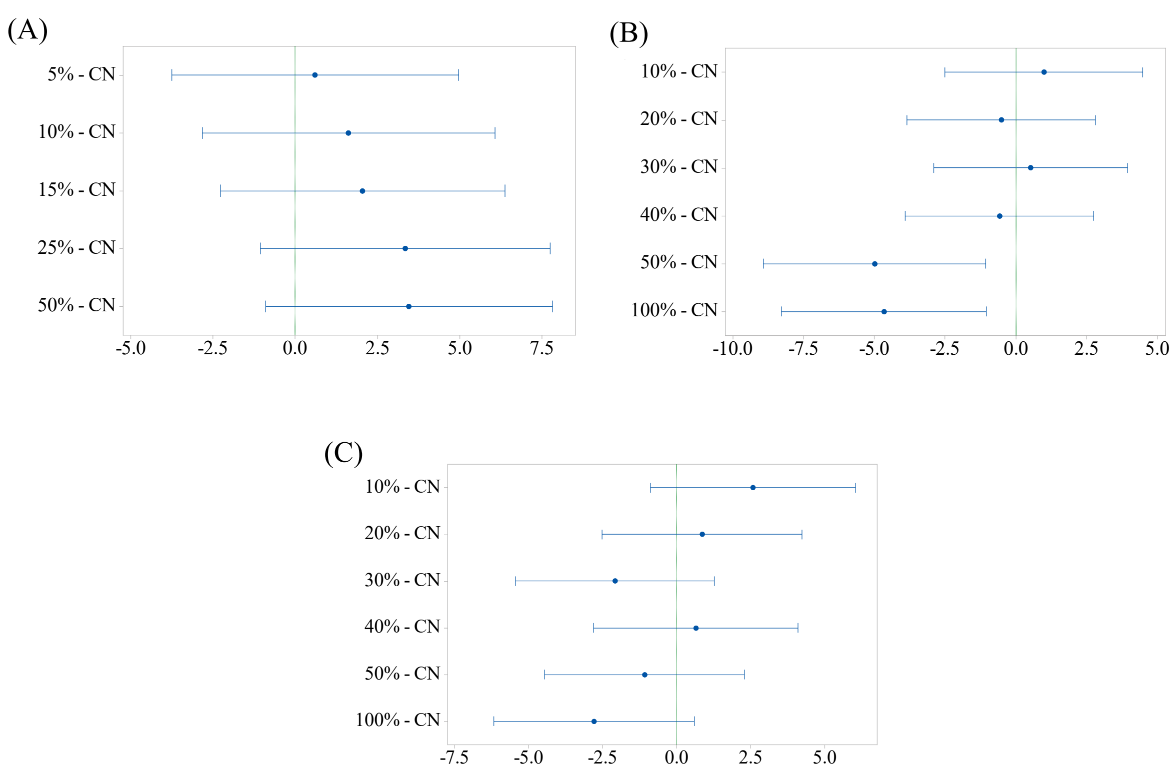

Figure 3 – Dunnett's test results for acute phytotoxicity using radish seed as a bioindicator with effluents: (A) Real; (B) Treated by Test 1; and (Cc) Treated by Test 2.

Table 7 – Results of the phytotoxicity test with different concentrations of sodium chloride and sodium sulfate using radish seeds.

NaCl	Concentration (M)	CN	0.12	0.14	0.16	0.18	0.20
	ML (cm)	10.13	5.82	3.15	3.30	2.60	2.10
	CV (%)	30.00	27.00	34.00	33.00	41.00	41.00
	GI (%)	100	53.61	31.08	31.48	24.80	19.34
	Effect	-	Phytotoxic	Phytotoxic	Phytotoxic	Very Phytotoxic	Very Phytotoxic
Na_2SO_4	Concentration (M)	CN	0.02	0.04	0.06	0.08	0.10
	ML (cm)	10.13	11.10	7.50	2.45	1.75	1.10
	CV (%)	30.00	30.00	32.00	49.00	34.00	55.00
	GI (%)	100	109.53	64.14	21.76	16.12	8.32
	Effect	-	Enhanced germination	Moderately phytotoxic	Very Phytotoxic	Very Phytotoxic	Very Phytotoxic

ML: medium length; CV: coefficient of variation; GI: germination index; CN: negative control; NaCl: sodium chloride; Na_2SO_4: sodium sulfate.

Significant differences were found between these samples and the negative control. The results were in line with those obtained by Cesário (2017) and Moraes Júnior and Bidoia (2015), who used NaCl and Na_2SO_4 in phytotoxicity tests, also observing the toxicity of these substances when in contact with plant organisms.

From the dose x response relationship presented in Figure 4, the IC50 of 0.1210 M was obtained using a polynomial distribution with a regression fit (R^2) of 90%. It indicates an increase in the toxic effects of NaCl as the concentration increases. Based on the IC50, it is possible to identify the sensitivity of the radish seed to the phytotoxic effects of NaCl present in the textile effluent.

NaCl toxicity to radish occurs at all concentrations, affecting seedlings' growth. It is proven that there is no significant similarity between the negative control and the Dunnett's test (α=0.05). The samples reveal a progressive reduction in the average size of the seedlings.

The toxic effects of NaCl on seed germination can be explained by the reduction in osmotic potential caused by salt accumulation in the roots during their early stages of development. Therefore, it can inhibit seed reserve mobility, affecting the number of germinated seeds and the time required for germination (Hadjadj et al., 2022).

Based on the dose x response relationship, shown in Figure 5, the IC50 was determined using a polynomial distribution with a regression fit (R^2) of 98.9%.

The concentration of Na_2SO_4 capable of inhibiting radish seedling growth by 50% was obtained from the curve (Figure 5), which received a value of 0.045 M. This curve fitted the data well with an R^2 of 99.1%. It can be seen in the Dunnett test (α=0.05) since there is no significant similarity between the negative control and all the seed germination inhibition concentrations (concentration values higher than 0.045 M).

Türkyilmaz (2022) carried out a phytotoxicity test with dry cress seed (*Lepidium sativum*) in a textile effluent treated by the synergistic activities of the oxidizing agent chlorine under Fe^{+2} catalysis and ultraviolet light for the removal of the synthetic dyes Acid Black 220, Bemacid Red, and Bemacid Blue used in the dyeing of polyamide textile products.

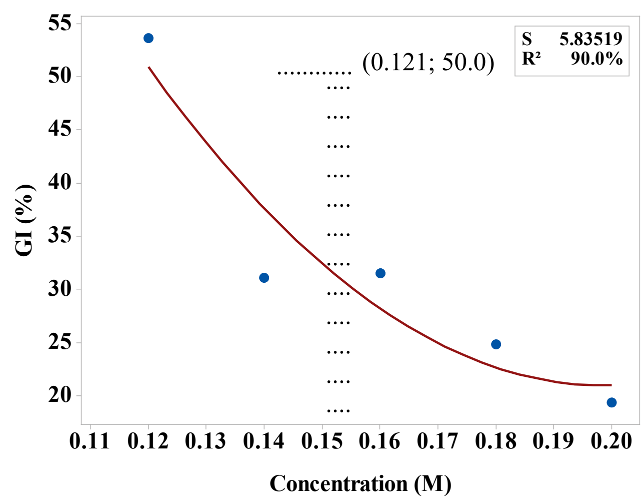

Figure 4 – Inhibitory concentration of 50% for sodium chloride (NaCl) and radish seeds based on the dose (NaCl concentration) × response germination index relationship.
R^2: coefficient of determination; S: residuals.

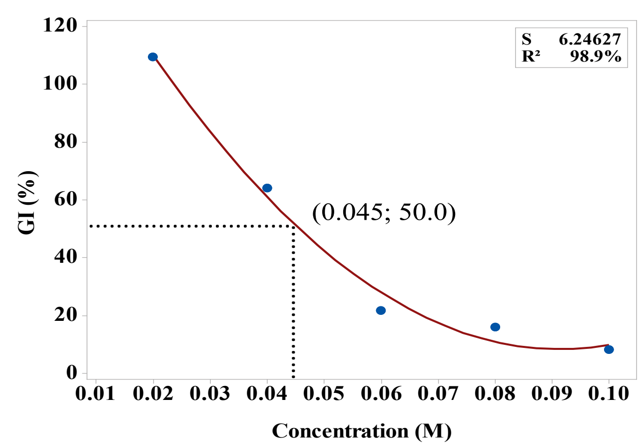

Figure 5 – Inhibitory concentration of 50% for Na_2SO_4 and radish seeds based on the dose (Na_2SO_4 concentration) × response (G.I.) relationship.
R^2: coefficient of determination; S: residuals.

The germination rate achieved in the raw effluent was 56%. In the toxicity tests carried out with the reference toxic substance (positive control) $ZnSO_4.7H_2O$, the IC50 values for 24, 48, and 72h of seed germination of the raw wastewater sample were calculated as 0.0183, 0.04, and 0.0625 M, respectively.

Conclusions

Phytotoxicity analyzes the intoxication of plants by toxic substances present in the growth medium when these substances accumulate in the plant's tissues. Therefore, from the bioassays using real textile effluent, it was observed that prior treatment of textile effluent before its final disposal is necessary since it can be harmful to the environment and inhibit seed germination, as was the case with cucumber.

It was also found that increasing the concentration of the salts studied resulted in increased toxicity to the seeds, negatively impacting their germination. This highlights the importance of rigorously monitoring the use of these substances in the textile industry to fix color in fabrics, as high concentrations of NaCl and Na_2SO_4 can lead to adverse effects on biodiversity and different ecological constituents, resulting in an imbalance in environmental homeostasis. For this reason, it is recommended that salts be removed from textile effluents, that environmental processing methods that reduce salt consumption be implemented, and that more neutral operations be used in this industry.

It is also suggested that chronic phytotoxicity tests be carried out to confirm the germination potential of cucumber and radish seeds with the treated effluent, verify the plant's longer life cycle, verify a more significant influence on seed germination, and contribute to environmental quality. Therefore, phytotoxicity assessment is a powerful tool for analyzing the impact of contaminants in textile effluents on plant organisms and the environment since there is no actual dimension to these toxicity levels in the various environmental matrices.

Authors' Contributions

Teixeira, L.M.: investigation, writing – original draft; formal analysis; data curation. **Quirino**, A.G.C.: conceptualization, formal analysis. **Aguiar**, H.L.S.: methodology; visualization; investigation. **Rocha**, E.M.R.: project administration; supervision; validation; writing – review & editing.

References

Al-Ansari, M. M.; Li, Z.; Masood, A.; Rajaselvam, J., 2022. Decolorization of azo dye using a batch bioreactor by an Indigenous bacterium Enterobacter aerogenes ES014 from the wastewater dye effluent and toxicity analysis. Environmental Research, v. 205, 112189. https://doi.org/10.1016/j.envres.2021.112189.

Associação Brasileira da Indústria Têxtil (ABIT), 2022. Indústria têxtil e de confecção faturou R$ 194 bilhões em 2021 (Accessed August 18, 2023) at:. https://www.abit.org.br/noticias/industria-textil-e-de-confeccao-faturou-r-194-bilhoes-em-2021.

Cesário, G.C., 2017. Fitotoxicidade de efluente de tingimentos têxteis realizados com ciclodextrina. Trabalho de conclusão de curso, Universidade Tecnológica Federal do Paraná, Apucarana. Retrieved 2017-12-01, from http://repositorio.utfpr.edu.br/jspui/handle/1/5730

Dhaouefi, Z.; Toledo-Cervantes, A.; Ghedira, K.; Chekir-Ghedira, L.; Muñoz, R., 2019. Decolorization and phytotoxicity reduction in an innovative anaerobic/aerobic photobioreactor treating textile wastewater. Chemosphere, v. 234, 356-364. https://doi.org/10.1016/j.chemosphere.2019.06.106.

Dutta, S.; Bhattacharjee, J., 2022. A comparative study between physicochemical and biological methods for effectively removing textile dye from wastewater. In: Shah, M.P.; Rodriguez-Couto, S.; Kapoor, R.T. Development in Wastewater Treatment Research and Processes. Elsevier, Haldia, India, pp. 1-21. https://doi.org/10.1016/B978-0-323-85657-7.00003-1.

Engelhardt, M.M.; Lima, F.R.D.; Martins, G.C.; Vasques, I.C.F.; Silva, A.O.; Oliveira, J.R.; Reis, R.H.C.L.; Guilherme, L.R.G.; Marques, J.J.G.S.M, 2020. Fitotoxicidade do cobre em culturas agrícolas cultivadas em solos tropicais. Semina: Ciências Agrárias, Londrina, v. 41 (6), Suplemento 2, 2883-2393. https://doi.org/10.5433/1679-0359.2020v41n6Supl2p2883.

Hadjadj, S.; Sekerifa, B.B.; Khellafi, H.; Krama, K.; Rahmani, S.; El Hadj-Khelil, A.O., 2022. Salinity and type of salt affect seed germination characteristics of the medicinal plant *Zygophyllum album* L. (Zygophyllaceae), native to the Algerian Sahara. Journal of Applied Research on Medicinal and Aromatic Plants, v. 31, 100412. https://doi.org/10.1016/j.jarmap.2022.100412.

Hoss, L.; Loebens, L.; Dos Santos, N.R.; Schoeler, G.P.; Silveira, M., 2019. Efeito da ozonização na fitotoxicidade de lixiviado de aterro sanitário. Congresso Sul-Americano De Resíduos Sólidos e Sustentabilidade (ConReSol); 2019 30-May; Foz do Iguaçu, Brazil. 1-6 p.

Li, M.; Li, K.; Wang, L.; Zhang, X., 2020. Feasibility of concentrating textile wastewater using a hybrid forward osmosis-membrane distillation (FO-MD) process: Performance and economic evaluation. Water Research, v. 172, 115488. https://doi.org/10.1016/j.watres.2020.115488.

Ma, D.; Yi, H.; Lai, C.; Liu, X.; Huo, X.; An, Z.; Yang, L., 2021. A critical review of advanced oxidation processes in organic wastewater treatment. Chemosphere, v. 275, 130104. https://doi.org/10.1016/j.chemosphere.2021.130104.

Mohamed, W.A.; Abd El-Gawad, H.H.; Handal, H.T.; Galal, H.R.; Mousa, H.A.; Elsayed, B.A.; Abdel-Mottaleb, M.S.A., 2023. TiO_2 quantum dots: Energy consumption cost, germination, phytotoxicity studies, recycling photo and solar catalytic processes of reactive yellow 145 dye and natural industrial wastewater. Advanced Powder Technology, v. 34 (1), 103923. https://doi.org/10.1016/j.apt.2022.103923.

Moraes Júnior, J.R.; Bidoia, E.D., 2015. Color degradation of simulated textile effluent by electrolytic treatment and ecotoxicological evaluation. Water Air Soil Pollution, v. 226, 402. https://doi.org/10.1007/s11270-015-2665-2.

Nidheesh, P.V.; Ravindran, V.; Gopinath, A.; Kumar, M.S., 2022. Emerging technologies for mixed industrial wastewater treatment in developing countries: an overview. Environmental Quality Management, v. 31 (3), 121-141. https://doi.org/10.1002/TQEM.21762.

Oyeniran, D.O.; Sogbanmu, T.O.; Adesalu, T.A., 2021. Antibiotics, algal evaluations, the acute effects of abattoir wastewater on liver function enzymes, genetic and haematologic biomarkers in the freshwater fish, *Clarias gariepinus*. Ecotoxicology and Environmental Safety, v. 212, 111982. https://doi.org/10.1016/j.ecoenv.2021.111982.

Peduto, T.A.G.; Jesus, T.A.D.; Kohatsu, M.Y., 2019. Sensibilidade de diferentes sementes em ensaio de fitotoxicidade. Revista Brasileira de Ciência, Tecnologia e Inovação, v. 4, (2), 200-212. https://doi.org/10.18554/rbcti.v4i2.3698.

Rahmani, A.R.; Mousavi-Tashar, A.; Masoumi, Z.; Azarian, G., 2019 Integrated advanced oxidation process, sono-Fenton treatment, for mineralization and volume reduction of activated sludge. Ecotoxicology and Environmental Safety, v. 168, 120-126. https://doi.org/10.1016/j.ecoenv.2018.10.069.

Rocha, E.M.R.; Lucena, L.G.; de Almeida Porto, C., 2020. Otimização do processo foto-fenton solar no tratamento de lixiviados de aterros sanitários. Revista Tecnologia e Sociedade, v. 16 (41), 202-215. https://doi.org/10.3895/rts.v16n41.11797.

Samuchiwal, S.; Gola, D.; Malik, A., 2021. Decolorization of textile effluent using native microbial consortium enriched from textile industry effluent. Journal of Hazardous Materials, v. 402, 123835. https://doi.org/10.1016/j.jhazmat.2020.123835.

Saravanakumar, K.; De Silva, S.; Santosh, S.S.; Sathiyaseelan, A.; Ganeshalingam, A.; Jamla, M.; Wang, M.H., 2022. Impact of industrial effluents on the environment and human health and their remediation using MOFs-based hybrid membrane filtration techniques. Chemosphere, v. 307, 135593. https://doi.org/10.1016/j.chemosphere.2022.135593.

Singha, K.; Pandit, P.; Maity, S.; Sharma, S.R., 2021. Harmful environmental effects for textile chemical dyeing practice. In: Ibrahim, N.; Hussain, C.M. Green Chemistry for Sustainable Textiles. Woodhead Publishing, Patna, pp. 153-164. https://doi.org/10.1016/B978-0-323-85204-3.00005-1.

Soares, M.R.; Matsinhe, C.; Belo, S.; Quina, M.J.; Quinta-Ferreira, R., 2013. Phytotoxicity evolution of biowastes undergoing aerobic decomposition. Journal of Waste Management, v. 2013 (1), 479126. https://doi.org/10.1155/2013/479126.

Sobrero, M.C.; Ronco, A., 2004. Ensayo de toxicidade aguda com semillas de lechuga (*Lactuca sativa* L). In: Castillo, G. (Ed.), Ensayos toxicológicos y métodos de evaluación de calidad de águas. International Development Research Centre (IDRC), Ottawa, pp. 71-79.

Türkyilmaz, M., 2022. A comparative study of free chlorine activated by Fe+2 and U.V. C light catalysts in treating real and simulated textile wastewater: Optimization, reactive species, and phytotoxicity assessment. Journal of Water Process Engineering, v. 49, p. 103161. https://doi.org/10.1016/j.jwpe.2022.103161.

Viana, G.C.C.; Rocha, E.M.R.; Scapin, E.; Cahino, A.; Leite, I.R.D.; Bertuol, D. A.; Amorim, C.C., 2023. Solar photocatalysis using post-consumer alkaline batteries degrades contaminants of emerging surface water concerns. Journal of Environmental Chemical Engineering, v. 11, (6), 111226. https://doi.org/10.1016/j.jece.2023.111226.

Waghmode, T.R.; Kurade, M.B.; Sapkal, R.T.; Bhosale, C.H.; Jeon, B.H.; Govindwar, S.P., 2019. Sequential photocatalysis and biological treatment for the enhanced degradation of the persistent azo dye methyl red. Journal of Hazardous Materials, v. 371, 115-122. https://doi.org/10.1016/j.jhazmat.2019.03.004.

Zucconi, F. (Ed.)., 1981. Regulation of abscission in growing fruit. Symposium on Growth Regulators in Fruit Production; 1981 30- Jun; Ithaca, USA. ISHS Acta Horticulturae 120: L.C. Luckwill. 89-94 p.

Zou, H.; Ning, X.A.; Wang, Y.; Zhou, F., 2019. The agricultural use potential of the detoxified textile dyeing sludge by integrated Ultrasound/Fenton-like process: a comparative study. Ecotoxicology and Environmental Safety, v. 172, 26-32. https://doi.org/10.1016/j.ecoenv.2019.01.020.