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Use of *Tradescantia pallida* for Genotoxic Evaluation of Water from a Lagoon in an Ecological Park in the Interior of Ceará

Uso da *Tradescantia pallida* para Avaliação Genotóxica da Água de uma Lagoa do Parque Ecológico no Interior do Ceará

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Abstract

Water quality is a determining factor for public health and the maintenance of ecosystems, especially in urban areas where anthropogenic pressure intensifies environmental degradation processes. In the municipality of Juazeiro do Norte (CE), the Lagoa dos Macacos, located in the Timbaúbas Ecological Park, has a history of environmental impacts related to irregular occupation and effluent discharge, highlighting the need for assessments that go beyond traditional physicochemical analyses. In this context, the use of bioindicators emerges as an efficient alternative for detecting compounds capable of causing genetic damage. Therefore, this study aimed to analyze evidence of genotoxicity in the water of the aforementioned lagoon using the Trad-MCN bioassay. This is an experimental, exploratory, and quantitative study, conducted in a laboratory, in which samples collected at two points in the lagoon were analyzed for physicochemical parameters and subsequently used to expose plants. The frequency of micronuclei was used as an indicator of chromosomal damage. The results showed a significant difference only between the negative and positive controls, confirming the sensitivity of the bioassay, while the environmental samples did not show statistically significant differences compared to the negative control. These findings highlight the importance of biological

monitoring as a complementary tool in water quality assessment and reinforce the need for future investigations that integrate biomarkers and chemical analyses for a better understanding of contaminant dynamics in the studied ecosystem.

Keywords: Water Quality. Genotoxicity. Bioindicators. Timbaúbas Park.

Resumo

A qualidade da água é um fator determinante para a saúde pública e para a manutenção dos ecossistemas, especialmente em áreas urbanas onde a pressão antrópica intensifica os processos de degradação ambiental. No município de Juazeiro do Norte (CE), a Lagoa dos Macacos, localizada no Parque Ecológico das Timbaúbas, apresenta histórico de impactos ambientais relacionados à ocupação irregular e ao lançamento de efluentes, evidenciando a necessidade de avaliações que ultrapassem análises físico-químicas tradicionais. Nesse contexto, o uso de bioindicadores surge como alternativa eficiente para a detecção de compostos capazes de provocar danos genéticos. Diante disso, o presente estudo teve como objetivo analisar indícios de genotoxicidade na água da referida lagoa por meio do bioensaio Trad-MCN. Trata-se de um estudo experimental, exploratório e quantitativo, conduzido em laboratório, no qual amostras coletadas em dois pontos da lagoa foram analisadas quanto a parâmetros físico-químicos e posteriormente empregadas na exposição das plantas. A frequência de micronúcleos foi utilizada como indicador de danos cromossômicos. Os resultados evidenciaram diferença significativa apenas entre o controle negativo e o controle positivo, confirmando a sensibilidade do bioensaio, enquanto as amostras ambientais não apresentaram diferenças estatisticamente significativas em relação ao controle negativo. Esses achados destacam a importância do monitoramento biológico como ferramenta complementar na avaliação da qualidade da água e reforçam a necessidade de investigações futuras que integrem biomarcadores e análises químicas para melhor compreensão da dinâmica de contaminantes no ecossistema estudado.

Palavras-chave: Qualidade da Água. Genotoxicidade. Bioindicadores. Parque das Timbaúbas.

1 Introduction

Water is an essential resource to life, the availability of which represents a basic right and a public health issue. Therefore, avoiding its pollution and waste is fundamental to maintain its quality and preserve ecosystems (Souza *et al.*, 2022). It is estimated that about 80% of diseases and 65% of hospital admissions are associated with contaminated water consumption (Brasil, 2004). This scenario is often related to the lack of basic sanitation, which directly affects the most vulnerable populations (Fortes; Barrocas; Kligerman, 2019).

The quality of water resources is an important indicator of environmental conditions, being compromised when physical-chemical and biological parameters exceed the limits established by the current legislation (Mothé *et al.*, 2025). An example of this is the city of Juazeiro do Norte, located in the interior of Ceará (CE), where the pollution of surface waters has also compromised the groundwater (Moreira *et al.*, 2023). Thus, highlighting the need for monitoring and monitoring of these sources (Alves *et al.*, 2017).

In this context, stands out the Ecological Park of Timbaúbas, located in the said municipality,

built near the rivers Salgadinho and Timbaúbas. The park represents the largest green area of Juazeiro do Norte, housing a significant diversity of fauna and flora (Nascimento; Rocha; Nascimento, 2015). In addition, it houses underground reserves with deep wells responsible for the water supply of the municipality. However, these resources have been threatened by the presence of solid waste, urban invasion and environmental degradation (Moreira A. *et al.*, 2023).

In view of this reality, it became essential to monitor water quality, as established by CONAMA Resolution No. 357/2005, which provides on the classification of water bodies and the effluent release standards, seeking to preserve the integrity of the water sources used for supply (CONAMA, 2005). Click or tap here to enter the text. However, this resolution does not include evaluations of genotoxic potential. In addition, no studies were identified that evaluated these effects on surface or groundwater of Juazeiro do Norte, evidencing an important gap in the local scientific literature (Brasil, 2021).

Among the methods of environmental evaluation, the use of bioindicators constitutes an effective approach to evaluate water quality (Khosrovyan *et al.*, 2022). These indicators enable contaminant detection and provide relevant information about ecosystem health, contributing to more efficient monitoring (Semeniuk, 2023).

In this sense, plants sensitive to environmental changes can be used in this type of monitoring, complementing traditional research and allowing the detection of environmental impacts (Jung *et al.*, 2023). In this context, the species *Tradescantia pallida* stands out, widely used in the micronuclei assay in *Tradescantia* (Trad-MCN), due to its high sensitivity to pollutants (Santos *et al.*, 2020).

This species presents advantages such as low cost, rapid propagation, precision and simplicity in the detection of genetic markers, besides being easily cultivated and adaptable to different climatic conditions (Santos *et al.*, 2019). Among these markers, the micronucleus are highlighted, defined as small accessory nuclei formed by fragments of chromosomes or whole chromosomes that are not incorporated into the main nucleus during cell division (Schmidt; Wolski, 2024).

Thus, this study aimed to evaluate signs of genotoxicity in the water of the Lagoon of the Ecological Park of Timbaúbas, in Juazeiro do Norte - CE, through the bioassay with *Tradescantia pallida*. It starts from the hypothesis that the lagoon water presents compounds with genotoxic potential capable of inducing the formation of micronuclei in cells of the bioindicator species.

2 Material and Methods

This is an experimental, exploratory and quantitative study (Lozada; Nunes, 2019), conducted in the laboratories of the Centro Universitário Paraíso (UniFAP), in Juazeiro do Norte, CE.

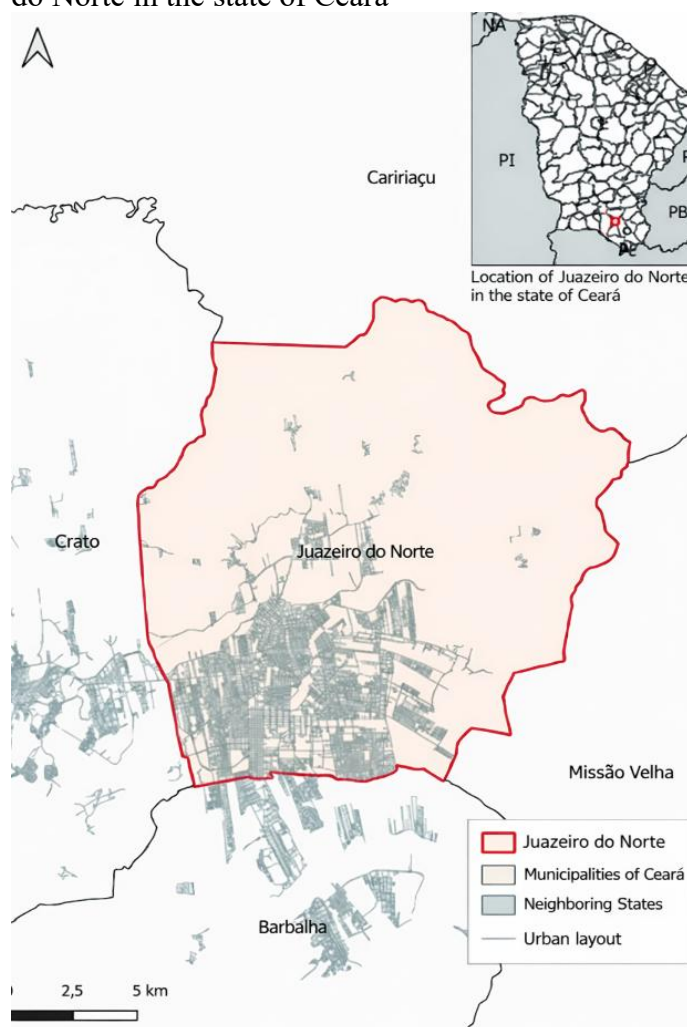
The methodology adopted corresponds to an adaptation of the methodological proposal of Ma

(1983), adjusted to the conditions of this experiment.

2.1 Water collection

Water samples were collected in Lagoa dos Macacos, from the Ecological Park of Timbaúbas, located in the municipality of Juazeiro do Norte - CE, Brazil. whose geographic coordinates of the park are 7.235857° S and 39.310471° W. The municipality belongs to the macroregion of South of Ceará State and integrates the Cariri microregion, as shown in Figure 1.

Figure 1 – Location of the municipality of Juazeiro do Norte in the state of Ceará



Source: Ribeiro, Donegan e Vidal (2022).

The collections were carried out in two distinct points of the lagoon, as highlighted in Figure 2. One of the points was positioned in an area near the entrance of urban effluents (P1 – point 1), while the other point was located in a region further away from this direct influence (P2 – point 2).

**Figure 2 - Lagoa dos Macacos
Collection Points (P1 and P2)**



Source: Based on Moreira *et al.* (2024).

In order to assist in the interpretation of the effects observed in biological analyzes, the samples collected were submitted to a physical-chemical characterization, each being analyzed in triplicate. After the collection, the samples were taken to the laboratory of the Centro Universitário Paraíso – UniFap and the tests were performed.

The analyzes were performed considering the parameters of pH, temperature, chloride and hardness, following the procedures described in the Practical Manual of Water Analysis of the National Health Foundation (FUNASA, 2013). Then, the results were compared to the standards established by CONAMA Resolution No. 357/2005 for Class 1 water bodies and, in the specific case of hardness, the classification ranges presented in the document Surveillance and Control of Water Quality for Human Consumption of the Ministry of Health (Brasil, 2006).

2.2 Collection and cultivation of the plant *Tradescantia pallida*

The collection was carried out by means of the stems cutting technique, using specimens of *Tradescantia pallida*, whose identification was reference the registration RSPF00004097 of the Virtual Herbarium. For this purpose, healthy stems, approximately 10 to 15 cm long, were carefully selected and removed from a matrix plant, to compose nine seedlings. Then, they were grown in 950

mL pots containing standardized substrate, composed of soil, organic compound, carnaúba bagana, bone meal and ammonium sulfate (Ma, 1983).

To monitor the conditions to which the seedlings were exposed, the temperature and humidity were recorded daily with the use of a digital thermometer and hygrometer. Likewise, the frequency of irrigation was controlled, since it occurred once a day, keeping the soil slightly moist (Ma, 1983). The plants were kept under sunlight in order to preserve photosynthetic capacity in the conditions closest to the natural environment, as shown in Figure 3.

Figure 3 – *Tradescantia pallida* seedlings



Source: research data.

2.3 Experimental groups

The experimental groups and control groups were defined in order to allow the comparison of the results and validate the response of the plant against the different types of exposure. The organization of these groups is described in Table 1.

Table 1 – Organization of *Tradescantia pallida* exhibition groups

Group	Number of seedlings used	Solution in Contact
Samples	2	Water to be analyzed
Positive control	1	Chloroform
Negative control	1	Distilled water

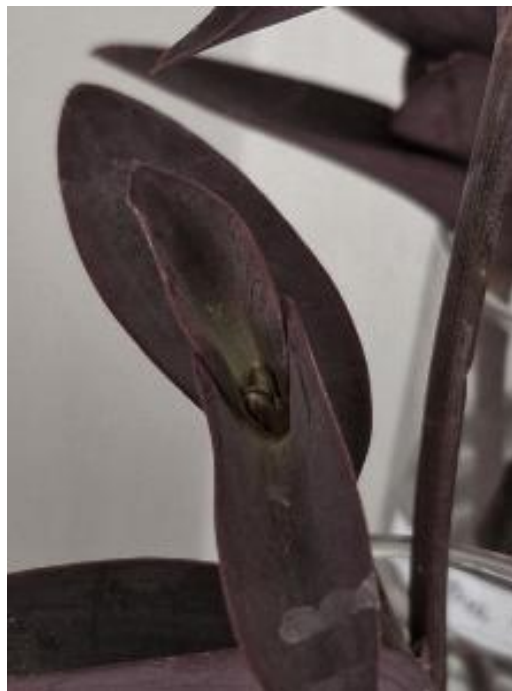
Source: research data.

The table presented earlier demonstrates the organization of the exposure groups, considering the solution with which the rods came into contact.

2.4 Poisoning

The stems were collected when they presented floral buds under development, as shown in Figure 4, being immediately separated in the positive control, negative control and experimental groups. Initially, they remained in distilled water for 24 hours, corresponding to the adaptive phase. Then each group was exposed to their respective solution for eight hours. After this phase, the stems returned to distilled water, remaining separated, characterizing the recovery period.

Figure 4 - Young inflorescence



Source: the authors.

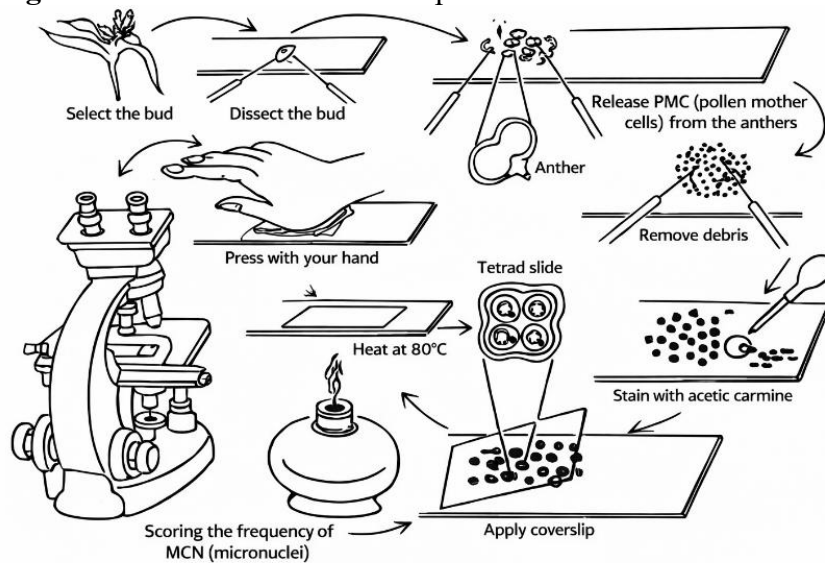
2.5 Fixing and staining

The stems of *Tradescantia pallida* containing flower buds in tetrad stage were submitted to the fixation process, using the solution of Carnoy, prepared in the ratio 3:1 of absolute ethyl alcohol to glacial acetic acid. After 24 hours, the samples were stored in 70% ethanol. Subsequently, the slides were stained with appropriate dye, as described by Macena and Boina (2018).

2.6 Preparation of blades and microscopic analysis

With the aid of a tweezers, the mother cells of the pollen grain were removed from the inside of the floral button and placed on identified blades, adding a drop of the acetic carmine dye at 2%. Then the blades received laminules and were heated under Bunsen's beak for 5 seconds. Subsequently, the samples were analyzed using an optical microscope, under 400× magnification, for the counting of the frequency of microcores (MCNs). This process is illustrated in Figure 5.

Figure 5 - Trad-MCN illustrative process



Source: Ma (1981).

For the analysis, MCNs were considered all structures with size between $1/3$ and $1/5$ of the main nucleus, with color and distribution of chromatin similar to those of the nucleus, and were disconnected from it (Pereira; Morelli, 2013). Five blades were prepared for each sample, in which 300 tetrads were analyzed per blade, totaling 1,500 tetrads per group.

The structures observed were classified as normal (without microcores) or abnormal, the latter being subdivided into five classes according to the number of micronuclei present: class I (tetrads with a microcore), class II (with two), class III (with three), class IV (with four) and class V (with five or more microcores). These counts were recorded in the “MCNs Score Sheet” presented in Table 1, based on the model described by Ma (1983).

Table 1 – MCNs Scorecard

Microcore Score Sheet								
Code	Normal	I	II	III	IV	V	Total	%

Source: Ma-based (1983).

This analysis was conducted blindly, that is, the codes of the samples remained confidential during the counting, in order to avoid bias.

2.7 Statistical analysis

Initially, the data obtained were organized and tabulated in Microsoft Excel software. Subsequently, the frequency of CNM was determined from the total number of CNM observed per

slide, divided by the number of analyzed tetrads (Ma, 1981). Statistical analysis was performed using GraphPad Prism 8.0.1, using the Kruskal-Wallis test, followed by Dunn's multiple comparisons test with Bonferroni correction, adopting a significance level of $p < 0.05$.

3 Results and Discussion

The results of the physicochemical characterization, obtained at both points, can be verified in Tables 2 and 3. The data showed that the parameters remained within the limits recommended by the norms used as reference. Despite this, a higher concentration of chloride ions was observed at the point near the entrance of urban effluents (P1), which suggests anthropic influence. Previous studies in urban lagoons corroborate that the presence of domestic sewage tends to increase the concentration of chlorides (Lima *et al.*, 2018).

Table 2 – Physical-chemical parameters of the water collected in point 1

Sample	pH	Temperature(°C)	Hardness (mg/L CaCO ₃)	Chlorides (mg/L)
1.1	7.07	25.2	8.02	83.3
1.2	7.08	25.4	5.07	75.1
1.3	7.06	25.3	5.04	71.6
Average	7.07	25.3	6.04	76.7
Standard Deviation	0.01	0.10	1.71	6.0
Coefficient of Variation	0.14%	0.40%	28.3%	7.84%

Source: research data.

Table 3 – Physical-chemical parameters of the water collected in point 2

Sample	pH	Temperature(°C)	Hardness (mg/L CaCO ₃)	Chlorides (mg/L)
2.1	7.03	24.8	7.50	56.7
2.2	7.04	24.8	6.00	46.8
2.3	7.08	24.8	5.50	41.1
Average	7.05	24.8	6.33	48.2
Standard Deviation	0.0265	0	1.04	7.9
Coefficient of Variation	0.38%	0%	16.4%	16.4%

Source: research data.

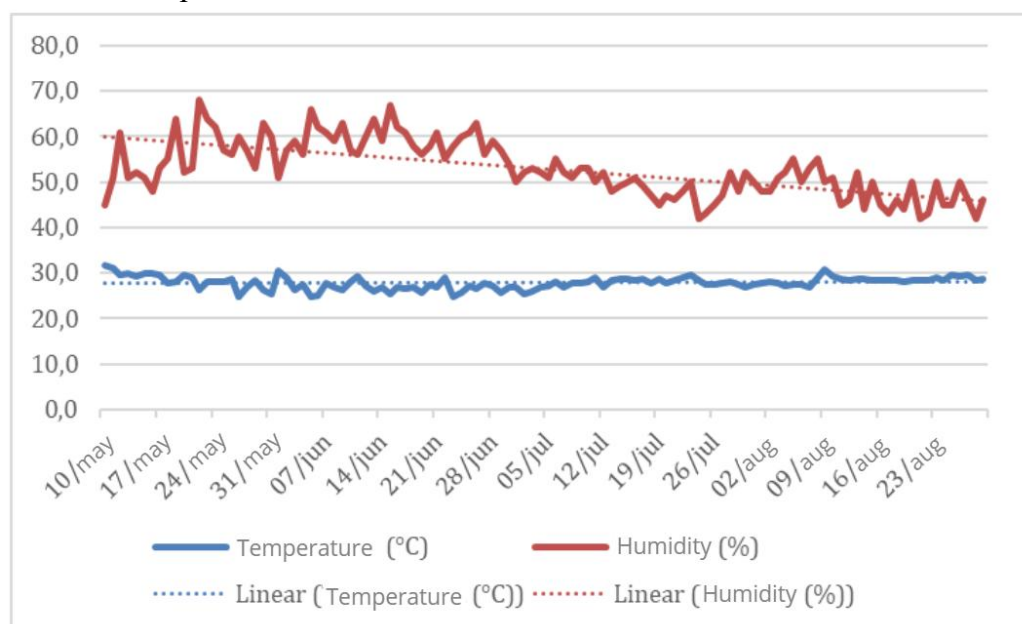
The study conducted by Moreira *et al.* (2024), performed in the same lagoon, evaluated parameters such as electrical conductivity, pH, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids, suspended solids, sedimentable solids, dissolved solids and temperature. The analyzes, carried out between November 2021 and March 2022, presented results in disagreement with the standards established by CONAMA Resolution

357/2005, with the exception of pH. Thus, although the physicochemical parameters evaluated in the present study are within the established limits, this does not ensure absence of contamination, since the absence of more comprehensive analyzes (metals, nutrients, DBO/COD, microbiology) limits a more integrated interpretation of water quality.

Physical-chemical parameters, alone, do not allow to identify compounds capable of inducing DNA damage, which is why biological tests, such as Trad-MCN, are essential to complement environmental monitoring (Jung *et al.*, 2023). Thus, while the physicochemical characterization provides an overview of water conditions, Trad-MCN adds information about its potential genotoxic effects, expanding the understanding of environmental quality.

Regarding the analysis of MCNs, the environmental conditions in which the seedlings of *Tradescantia pallida* remained exposed were considered, since external factors can influence the development of the reproductive structures used (Ma, 1983). During the cultivation period, from May 10 to August 29, 2025, the temperature and humidity parameters were monitored and recorded, as shown in Figure 1.

Chart 1 – Monitoring of environmental conditions during the period of cultivation of plants



Source: research data.

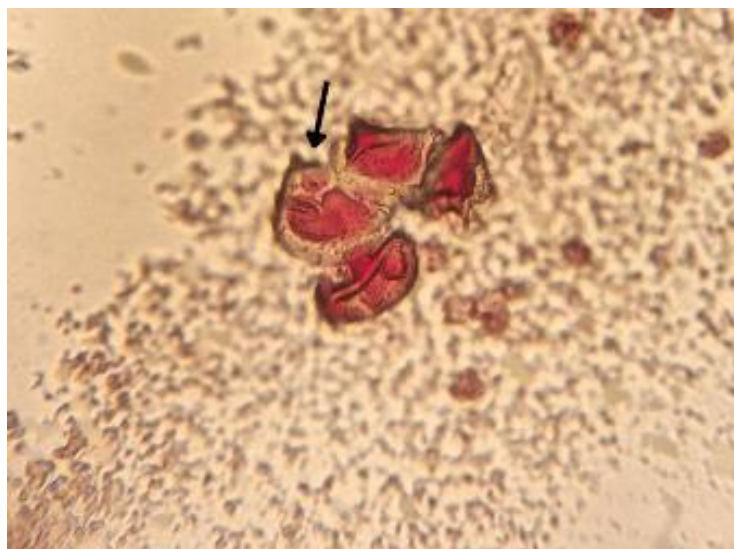
The records showed average temperature of 27.08 ± 1.06 °C and average relative humidity of $53 \pm 5.40\%$. Klumpp *et al.* (2004, 2006) point out that extreme temperatures can affect the development of the mother cells of pollen grains in *Tradescantia pallida*, increasing the frequency of mutations when exposed to low temperatures, such as 11 °C. Thus, the average temperature recorded in this study remained adequate for the growth and development of plant reproductive structures,

without prejudice to microscopic analysis.

Still according to Ma (1983), the ideal temperature should vary between 21 °C and 26 °C, and the relative humidity between 60% and 80%. Thus, it is noted that the records of the present study presented slightly higher temperatures and humidity below the recommended interval. Despite this, the presence of tetrads observed in the samples shows that such differences did not compromise the development of inflorescences, and the necessary structures for the analysis were observed (Ma, 1981). Similarly, the low variation of the parameters indicates that the conditions remained stable throughout the cultivation period. With the reproductive structures properly formed, the next stage of the study began.

The micronucleus analysis was performed in *Tradescantia pallida* cells in the tetrads stage, a post-meiotic phase where four nuclei derived from meiosis are within the same cellular structure (Ma, 1983). This stage is used in Trad-MCN bioassays because it allows a clearer visualization of the micronuclei from clastogenic or aneugenic events, which consist of breaks or errors of chromosomal segregation during meiotic cell division, thus being a sensitive biomarker of genetic damage (Sposito, 2017). An example of analyzed tetrad, highlighting a microcore, can be seen in Figure 6.

Figure 6 – A representative tetrad of sample 1 of the lagoon, with the presence of micronucleus

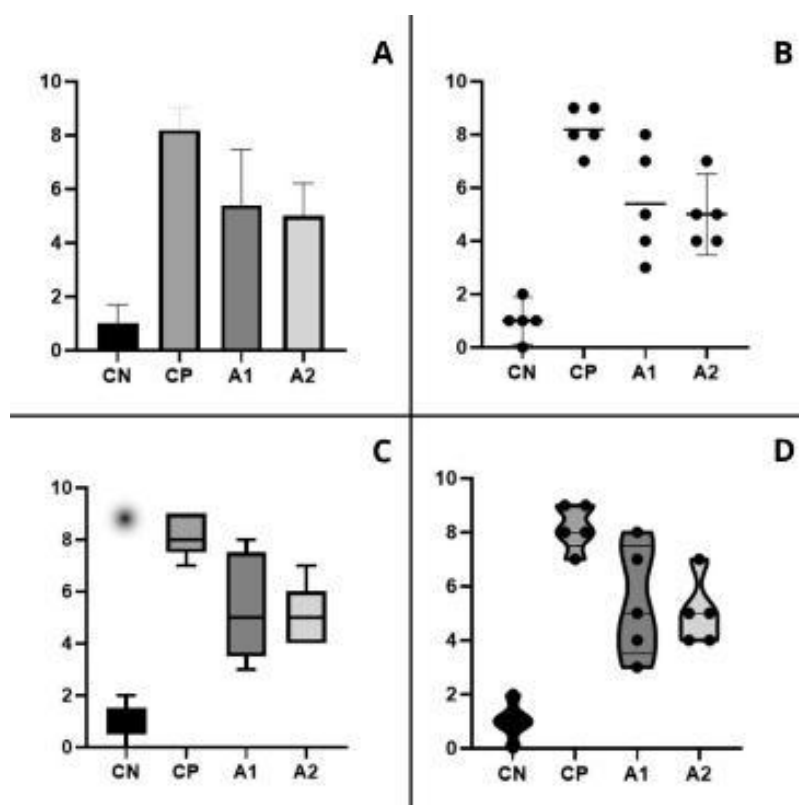


Source: research data.

Micronuclei count present in 300 tetrads per group was performed, totaling 1500 cells analyzed. A total of 5 microcores were observed in the negative control, 41 in the positive control, 27 in group A1 (sample 1) and 25 in group A2 (sample 2). In more detail, the number of MCNs per blade can be visualized in Figure 7, which gathers different charts representing the variation of the data between the slides and the statistical distribution of each experimental group.

The results obtained in this study indicated variations in the frequency of micronuclei in *Tradescantia pallida* between the analyzed groups. However, although the environmental samples had higher frequencies than the negative control, these differences were not statistically significant, suggesting only a possible influence of agents with genotoxic potential in the water samples evaluated. It is worth noting that, because it is a limited set of samples, restricted only to the specific points analyzed (P1 and P2) and the collection period, it is not possible to generalize the results for the entire lagoon. Thus, the conclusions reflect exclusively the conditions observed in this study.

Figure 7 – Frequency of microcores in *Tradescantia pallida*



The X-axis represents the experimental groups: CN = negative control; CP = positive control; A1 and A2 = water samples collected at the two defined points. The Y-axis indicates the amounts of microcores observed in 300 cells per slide. (A) Average of MCN; (B) distribution of individual values; (C) variation and dispersion; (D) overall distribution of values.

Source: research data.

The charts presented above demonstrate the variation in the frequency of micronuclei between the analyzed groups. The negative control (CN) presented the lowest values, indicating absence of genotoxic effect. The highest number of micronuclei was observed in the positive control (CP), as expected, confirming the sensitivity of the assay. The samples A1 and A2 presented higher frequencies of micronucleus than the negative control and lower than the positive control, indicating an intermediate variation in the response observed between the evaluated groups.

Statistical analyzes were conducted considering a significance level of $p < 0.05$. The Kruskal-Wallis test indicated a statistically significant difference among the four groups evaluated ($p=0.0017$), demonstrating that the median of the treatments are not equal. To identify which groups differed, the Dunn post-hoc test with Bonferroni correction was applied. The results showed a significant difference only between negative control (CN) and positive control (CP) ($p=0.0006$), confirming the efficacy of positive control and sensitivity of the Trad-MCN bioassay. The comparisons between negative control and environmental samples A1 ($p = 0.1630$) and A2 ($p=0.2772$), as well as between the other pairs of groups, did not show statistically significant differences.

Considering the results obtained between A1 and A2 of the two collection points of Lagoa dos Macacos, a small difference in the frequency of MCNs was observed. Although this numerical difference is discrete, both showed values higher than the negative control, indicating a trend of increase in the frequency of micronuclei in the environmental samples. The proximity of the results identified in these points may be related to the dynamics of dispersion of pollutants in the lagoon, since the movement of water favors the dissemination of the pollutants present (Silva; Santos, 2023).

Sample A1, corresponding to point P1, located closer to the effluent inlet, showed signs of greater anthropic influence compared to sample A2, collected from point P2 of the lagoon, which corresponds to the higher levels of chlorides observed in the physical-chemical analysis. Therefore, the results suggest that possible effects associated with the presence of contaminants may not be completely detected by conventional indicators (physical-chemical parameters), reinforcing the use of bioassays such as Trad-MCN in the evaluation of water quality (Ferreira *et al.*, 2020; Macena; Boina, 2018).

The reliability of Trad-MCN bioassay with *Tradescantia pallida* was strengthened by studies that expanded its applicability in different environmental scenarios. An example was the analysis conducted by Santos *et al.* (2019), carried out with samples from the Tiete River, in Cabreúva (SP), where the experimental sample presented 35 microcores, even exceeding the positive control (17 MCNs), showing a high genotoxic response. In the present study, the experimental groups (A1 = 27 MCNs and A2=25 MCNs MCNs) presented lower values than the positive control (41 MCNs), which indicates lower genotoxic response of the analyzed samples, although still higher than the negative control (5 MCNs).

In addition to the application in aquatic environments, Trad-MCN with *Tradescantia pallida* has also been effective in evaluating air quality. The study conducted by Campos *et al.* (2024) with passive biomonitoring performed in urban areas with different levels of traffic, it demonstrated that the frequency of micronuclei in the plant directly correlates with the concentration of particulate matter and chromium in the soil, validating its sensitivity to atmospheric pollutants.

There are studies that show that the city of Juazeiro do Norte faces serious challenges related to the quality of water intended for human consumption, especially because it depends exclusively on underground sources for public and private supply. In view of this, the absence of adequate basic sanitation, combined with the release of untreated domestic effluents in water bodies such as Lagoa dos Macacos, has favored the infiltration of pollutants in the aquifer that supplies the population (Gomes; Franca, 2019; Moreira A. *et al.*, 2023).

It is worth mentioning that the water of Lagoa dos Macacos has already demonstrated physical-chemical and microbiological parameters outside the legal standards (Moreira *et al.*, 2024), which represents a real risk to public health, especially in the presence of high levels of iron, total dissolved solids, manganese, electrical conductivity and nitrate, outside the potability standards, as verified by Formiga *et al.* (2020). The situation is aggravated by the absence of genotoxicity analysis in the protocols for monitoring water distributed by CAGACE (Water and Sewage Company of Ceará), which follows the GM/MS Ordinance N° 888/2021, having procedures for control and surveillance of water for human consumption (Brasil, 2021).

The results obtained in the present study by means of the Trad-MCN bioassay reinforce the importance of evaluating the water quality used by the population, by indicating variations in the frequency of micronuclei that may be associated with cellular responses related to genetic stress. Although no statistically significant differences were observed in relation to negative control, the results suggest the need for further investigations to evaluate the possible environmental and health impact associated with continuous exposure, which, in the long term, may be related to the development of mutations and chronic diseases (Silva *et al.*, 2013).

It is worth noting that genotoxic compounds can cause chromosomal breaks, losses of genetic material and genomic instability, resulting in mutations associated with neoplasms, reproductive alterations, endocrine disorders and other chronic diseases. This scenario becomes even more worrying in the context of Lagoa dos Macacos, where the population maintains direct contact with water through activities such as fishing and recreational use (Silva *et al.*, 2017). Thus, scientific evidence shows that environmental exposures at low concentrations of these agents can generate progressive effects over time, especially in situations of continuous contact with multiple contaminants (Sarpa; Friedrich, 2022).

The national epidemiological data, which associate inadequate sanitation with thousands of hospitalizations for water transmission diseases, show the relevance of monitoring water quality in vulnerable regions, such as the Northeast, which presents the highest rates of illness due to this type of exposure (Freitas; Magnabosco, 2025). In Ceará, recent studies indicate that several sources of supply present physicochemical nonconformities, reinforcing the need for continuous surveillance of

water resources (Gurgel *et al.*, 2024).

The possible presence of genotoxic agents in the water of Lagoa dos Macacos may pose a direct risk to the ecosystems of the Ecological Park of Timbaúbas, since aquatic and terrestrial organisms may suffer cellular alterations similar to those observed in the bioassay. According to Dourado *et al.* (2017), contaminants such as heavy metals and pesticides confer cytotoxic, genotoxic and mutagenic properties to water, causing DNA damage and chromosomal alterations in fish, as well as affecting physiological processes such as respiration and osmotic balance. These compounds also impact aquatic plants, reducing the mitotic index and inducing cellular anomalies that compromise their growth and development (Dourado *et al.*, 2017).

Genotoxic effects, even when subtle, may alter population dynamics by causing mutations capable of reducing the ability of organisms, affecting their survival or reproductive success and, consequently, the abundance of certain species over time (Johnson *et al.*, 2024). In addition, sensitive plant species around the lagoon can act as contamination sentinels, indicating that genotoxic compounds present in the water also reach the soil and nearby vegetation, compromising the ecological stability of the park as a whole (Adam *et al.*, 2023).

In this sense, the protection of springs, recharge areas and the water table associated with Parque das Timbaúbas is fundamental, especially because the local aquifer has a strategic role in the water supply of Juazeiro do Norte. Thus, the adoption of environmental management measures, such as control of pollution sources, expansion of basic sanitation and monitoring of water quality, is considered essential to prevent groundwater contamination (ANA, 2022). In addition, the presence of genotoxic compounds in surface water, if not controlled, may favor the migration of contaminants to the underground layers, especially in regions where infiltration occurs in an accelerated way due to disordered occupation and the absence of adequate sanitation (Moreira C. *et al.*, 2023).

The degradation of riparian vegetation compromises the natural capacity of the environment to retain and filter pollutants of diffuse origin, increasing the risk of continuous contamination of water bodies. Although, in the area of this study, the absence of basic sanitation represents the main factor associated with the contamination of the lagoon, the conservation of the riparian vegetation, combined with the proper management of the soil, constitutes an important complementary measure for the protection and improvement of water quality, contributing to water security and ecological balance of the studied area (Dosskey *et al.*, 2010).

In general, the results point to the need for continuous monitoring of Lagoa dos Macacos, considering not only physical-chemical parameters, but also biological indicators capable of revealing impacts underlying the ecosystem. In this context, studies involving ichthyofauna and other aquatic organisms that depend on this environment can provide relevant information on the effects of

contamination on the local biota. The combination of these approaches increases the capacity of environmental diagnosis and contributes to more effective strategies for protecting public health and conservation of the Timbaúbas Ecological Park.

The present study presents some limitations that should be considered in the interpretation of the results. Sampling was restricted to two specific points of the lagoon and a single collection period, not contemplating seasonal variations that may influence the dynamics of contaminants. Moreover, although Trad-MCN bioassay indicated signs of genotoxicity, no specific chemical analyzes were performed to identify the compounds responsible for the observed effects. The use of a single plant biomarker also limits direct extrapolation of results to human health risks or other ecosystem components. Future studies with spatial and temporal expansion of sampling, as well as integration with complementary chemical and ecotoxicological analyzes, are recommended to deepen the understanding of the environmental quality of Lagoa dos Macacos.

4 Conclusion

The results showed that although the physicochemical parameters analyzed were within the limits established by the legislation, the Trad-MCN bioassay with *Tradescantia pallida* indicated variations in the frequency of micronuclei in the analyzed samples. The MCNs frequencies observed in A1 and A2, numerically superior to the negative control, suggest the possible presence of agents with genotoxic potential in the water of Lagoa dos Macacos, although no statistically significant differences were observed between the evaluated groups.

These findings reinforce the sensitivity of *T. pallida* as a bioindicator and highlight the importance of the application of genotoxic biomarkers as a complementary tool in the monitoring of environmental quality. In addition, the study contributes to broaden the knowledge about the environmental quality of the lagoon and highlights the need for future investigations that integrate chemical analysis of contaminants, greater spatial and temporal coverage of sampling and the inclusion of other bioindicators.

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Declaration of Use of AI Tools

During the production process of this article, specifically in the spelling review and textual improvement step, the ChatGPT (OpenAI) tool was used exclusively to support spelling correction and adjustments. After the use of the tool, the authors reviewed, checked and edited the results fully, being fully responsible for the content presented here.

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