

Reuse of hydrogels from disposable diapers to enhance seedling development of Caatinga species

Reutilização de hidrogéis de fraldas descartáveis para potencializar o desenvolvimento de mudas de espécies da caatinga

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RESUMO

A fralda descartável é um resíduo comum e produzido em larga escala. Em sua constituição, estão os polímeros superabsorventes (hidrogel), que possuem capacidade de reter grandes quantidades de água e dispô-los de forma gradual. Dessa maneira, o objetivo deste trabalho foi avaliar a influência do uso do hidrogel proveniente de fraldas descartáveis já utilizadas para produção de mudas de *Libidibia ferrea*, *Mimosa caesalpinifolia* e *Poincianella pyramidalis*. O hidrogel extraído das fraldas descartáveis foi lavado e posteriormente colocado na estufa à temperatura de 80°C até ficar totalmente seco. Para o preparo do substrato, foram usados 8 kg de massa de solo, por unidade amostral, com 70% de solo e 30% de esterco bovino curtido. Foram feitos quatro tratamentos com cinco repetições: com hidrogel e irrigação diária (CH_ID); com hidrogel e irrigação a cada quatro dias (CH_I4D); sem hidrogel e irrigação diária (SH_ID); e sem hidrogel e irrigação a cada quatro dias (SH_I4D). O experimento durou três meses, sendo medidos mensalmente a altura e o diâmetro dos indivíduos, e, posteriormente, foram avaliados número de folhas (NF), teor de matéria seca das folhas (TMSF), do caule (TMSC) e do sistema radicular (TMSRS e TMSRP), além do comprimento da raiz primária (CR) e do Dickson *quality index* (DQI). Os resultados mostraram que a altura e o diâmetro das plantas foram favorecidos com a adição do hidrogel reutilizado. Em relação à biomassa, houve incremento do NF, TMSRS e CR em indivíduos de *L. ferrea*, TMSF e CR em indivíduos de *M. caesalpinifolia*, e NF e TMSF em indivíduos de *P. pyramidalis*. Os indivíduos de *M. caesalpinifolia* e *P. pyramidalis* apresentaram maior qualidade (DQI=1,65 e 3,54, respectivamente), principalmente no tratamento CH_I4D. Desse modo, o hidrogel reutilizado é indicado em situações de déficit hídrico para produção de mudas de qualidade.

Palavras-chave: resíduos sólidos; hidrogel; escassez hídrica; espécies nativas.

ABSTRACT

Disposable diapers, a common waste produced on a large scale, contain superabsorbent polymers (hydrogel) that can retain large quantities of water and dispose of it gradually. The aim of this study was to evaluate the influence of hydrogel usage from used disposable diapers on the production of *Libidibia ferrea*, *Mimosa caesalpinifolia*, and *Poincianella pyramidalis* seedlings. To prepare the hydrogel, the diapers were washed and dried in an oven at 80°C for 12 h. The substrate consisted of 8 kg of soil mass per sample unit, with 70% soil and 30% cured cattle manure. In total, four treatments were carried out with five replications: with hydrogel and daily irrigation (CH_ID); with hydrogel and irrigation every 4 days (CH_I4D); no hydrogel and daily irrigation (SH_ID); and no hydrogel and irrigation every 4 days (SH_I4D). The experiment lasted 3 months, during which the height and diameter of the seedlings were measured monthly, along with other parameters such as the number of leaves (NF), leaf dry matter content (LDMC), stem dry matter content (SDMC), root system dry matter content (SRDMC and PRDMC), the primary root length (PRL), and Dickson Quality Index (DQI). The results indicated that the addition of reused hydrogel enhanced the height and diameter of the plants. Regarding biomass, there was an increase in NF, SRDMC, and RL for *L. ferrea*, LDMC and RL for *M. caesalpinifolia*, and NF and LDMC for *P. pyramidalis*. The *M. caesalpinifolia* and *P. pyramidalis* seedlings exhibited higher quality (DQI of 1.65 and 3.54, respectively), particularly in the CH_I4D treatment. Based on these findings, the use of reused hydrogel is recommended for producing high-quality seedlings in water-deficit situations.

Keywords: solid waste; hydrogel; water scarcity; native species.

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INTRODUCTION

The growing demands of the population have led to a significant increase in waste production, resulting in various issues related to production methods and disposal practices. According to the study Panorama dos Resíduos Sólidos no Brasil, urban solid waste generation in Brazil rose from 66.7 million tons in 2010 to 82.5 million tons in 2020. The same study notes that each Brazilian generates, on average, 390 kg of urban solid waste per year, which translates to over 1 kg per day (Abrelpe, 2021). In light of this scenario, there is a need for research demonstrating the potential for reusing discarded materials.

One commonly produced waste item on a large scale is disposable diapers. Brazil ranks as the sixth largest global market for disposable diapers, with each child using an average of 3,000 diapers by the time they reach 3 years old (NASCIMENTO; BARROS, 2020). As a consequence of their use, 2 billion diapers are discarded in landfills each year, making them the third largest individual item by volume found in sanitary landfills, according to the National Information System on Sanitation (SNIS, 2017).

The production of disposable diapers requires substantial resources, and these items take many years to decompose after disposal (SILVA *et al.*, 2021). They consist of organic matter, plastics, superabsorbent substances, and fibers, all of which have significant recycling potential. These materials can be reused as raw materials for other products, helping to divert waste from landfills and incinerators (COLÓN *et al.*, 2011; ESPINOSA-VALDEMAR *et al.*, 2014).

Among the materials used in disposable diapers are superabsorbent polymers, which can retain large amounts of water (BOGO; ANCINI; SCHMIDT, 2023). These polymers can be transformed into hydrogels, which act as soil conditioners, improving porosity and serving as carriers of nutrients. They enable controlled release of nutrients and possess excellent cation exchange capacity, helping to minimize ion leaching (SARMAH; KARAK, 2020).

The use of commercial hydrogel in degraded soils aims to reduce the impacts of water deficit. Thus, hydrogel reduces the frequency of irrigation and the volume of water used, enhancing the efficiency of water runoff. This superabsorbent polymer is also used in the production of forest seedlings, including native species, often yielding satisfactory quality and growth results (ALBUQUERQUE *et al.*, 2024).

Several studies analyzed the influence of commercial hydrogel use on plant development. In this regard, Rondon Neto, Jesus, and Silva (2021), Mendes *et al.* (2022), and Antas *et al.* (2024), while investigating the use of hydrogel in the production of seedlings of *Mimosa caesalpinifolia* Benth. ("Sabia"), *Bauhinia unguulata* L. ("Pata de vaca"), and *Anadenanthera colubrina* (Vell.) ("Angico"), respectively, observed that the polymer favored the initial development of seedlings and enabled greater improvement in the analyzed characteristics. Furthermore, research focusing on dosage (DIÓGENES *et al.*, 2022) and irrigation interval (MONTEIRO NETO *et al.*, 2023; ANTAS *et al.*, 2024) has also been conducted.

Therefore, one of the best solutions for post-consumer diaper treatment is the use of the hydrogel contained within them for application in soil added to a substrate, acting as a conditioner. Its use is justified as it can increase water availability for plants and gradually release nutrients present in the soil, optimizing cultivation (PATRA *et al.*, 2022), while posing minimal risk of infiltration (QU; VARENNES, 2010). Consequently, the application of hydrogel in the production of seedlings from Caatinga species is of particular importance given the region's challenging environmental conditions, such as water scarcity and prolonged droughts, in addition to the specific adaptive traits of native plants.

Recent studies on plants from the Caatinga focused on their water absorption behavior, examining various aspects of seedling development and drought tolerance. For instance, research on *Libidibia ferrea* Mart. demonstrated that the seeds absorb water in a three-phase process, particularly after mechanical scarification. This process softens the seed coat, making it easier for the seeds to absorb water (CARVALHO *et al.*, 2017). Seedlings of *Poincianella pyramidalis* (Tul.) L. P. Queiroz, subjected to periods of water restriction, demonstrated physiological adjustments that help maintain a water potential conducive to water absorption. These adaptations include alterations in free proline levels, which are essential for osmotic regulation during water stress (FRANÇA *et al.*, 2020). Additionally, the plant employs strategies such as reducing transpiration and adjusting its root system to optimize water uptake under stressful conditions (LEITE *et al.*, 2020).

For *M. caesalpinifolia* Benth, studies have examined how seedlings respond to different water regimes, revealing that water deficit impairs growth and biomass accumulation (LEITE *et al.*, 2020). A study by Moura *et al.* (2011) demonstrated that water restriction, simulated using polyethylene glycol (PEG), reduced the germination rate at osmotic potentials lower than -0.5 MPa. Furthermore, *M. caesalpinifolia* showed reduced growth under both water and salt stress, with a decrease in the length of the aerial part and roots, as well as in dry matter accumulation, as osmotic potential decreased (NICOLAU *et al.*, 2020). These findings underscore the importance of water management for these species, particularly in regions with limited water availability, where their survival strategies are essential for growth and survival.

Based on the aforementioned, the objective of this study was to evaluate the influence of superabsorbent polymer use, derived from disposable diapers and added to the substrate, on the production and quality of seedlings of native plants from the Caatinga. Given the information on waste production and the application of commercial hydrogel in seedling production, it is expected that diaper hydrogel will enhance the development of Caatinga species seedlings, which inhabit environments with low water availability. If the hypothesis holds true, seedlings produced with diaper hydrogel will exhibit greater height and diameter growth, increased biomass investment, and overall higher quality.

METHOD

Location and selection of studied species

The study was conducted at the Instituto Federal de Educação, Ciência e Tecnologia do Ceará (IFCE). Planting took place at the Acopiara campus in a greenhouse with a roof that allows light penetration while preventing water entry. The climate in the Acopiara municipality is predominantly hot semi-arid tropical, with average temperatures ranging from 26 to 28°C and annual rainfall of 748.5 mm, occurring mainly from February to April (Ipece, 2017).

The species used in the experiment were *L. ferrea* Mart. ("Jucá"), *M. caesalpinifolia* Benth. ("Sabia"), and *P. pyramidalis* (Tul.) L. P. Queiroz ("Catingueira"). These species were chosen because they are native to the Caatinga and are used for the restoration of degraded areas, requiring the production of high-quality seedlings (ALVES *et al.*, 2019; BEZERRA *et al.*, 2019; PINTO *et al.*, 2020).

Seeds used in the experiment were collected from the Trussu District, located in Acopiara, Ceará. Seed collection was carried out at different times

and from different mother plants, after they had fallen to the ground. The first collection was made in August 2022 from individuals of *L. ferrea* and *M. caesalpinifolia*, and the second collection was performed in January 2023 from individuals of *P. pyramidalis*.

Seeds of *L. ferrea* and *M. caesalpinifolia* underwent pre-germination treatment involving chemical scarification with sulfuric acid (H_2SO_4) for 10 and 15 min, respectively (BRITO *et al.*, 2014; WALTER *et al.*, 2018). Seeds of *P. pyramidalis* underwent manual scarification of the seed coat with sandpaper No. 80 on the opposite side to the hilum (MATIAS; SILVA; DANTAS, 2017). Dormancy-breaking procedures were conducted in the Biodiversity Laboratory at the IFCE Acopiara campus.

Water absorption tests

All hydrogel extractions were conducted using Pampers® brand diapers, which incorporate polyacrylate as their superabsorbent polymer (PAMPERS, 2022). Hydrogel extraction was attempted using diapers from other brands; however, the results were unsatisfactory. These diapers contained a significant proportion of cotton, leading to hydrogel samples with a high content of natural fibers, which compromised the purity and quality of the extracted material.

The diapers used in this experiment were washed with tap water to remove superficial organic residues and impurities. This method was chosen to minimize water consumption, aligning with the study's commitment to sustainability. After that, they were cut open with scissors to remove the absorbent material, which was then collected into a container and homogenized. Drying was conducted in an oven at 80°C until the material was completely dry. The remaining material from the diapers was disinfected with alcohol and stored for disposal according to the waste management plan of the IFCE Quixadá campus (Figure 1).

Water absorption tests were conducted through swelling kinetics, which quantifies the volumetric expansion of a material, such as hydrogel, upon contact with water over a defined period of time. The initial mass of the hydrogel was 0.5 g, which was placed in contact with water in filtration crucibles. The hydrogel was then weighed on an analytical balance at intervals of 1, 5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100, and 120 min, observing the time at which the mass became constant. The tests were conducted in triplicates. The swelling capacity was determined by the ratio of the mass of water absorbed by the hydrogel to the mass of the dry hydrogel. Water absorption tests were conducted at the Chemistry Laboratory of the IFCE Quixadá campus.

Preparation of substrate and experimental development

The experiment was conducted in 10-L pots, with a standardized use of 8 kg of soil mass per sample unit, comprising 70% soil and 30% composted cattle manure. The experimental design was completely randomized in a 2 x 2 factorial arrangement. The treatments included with and without hydrogel, both with daily irrigation (CH_ID and SH_ID) and irrigation every 4 days (CH_I4D and SH_I4D), each with five replications. Each hydrogel treatment repetition received 5 g of the product diluted in 1 L of water. Repetitions of treatments without hydrogel received only 1 L of water. After planting the seeds, 1.5 L of water, without hydrogel, was added to each pot until field capacity was reached. Subsequent irrigations used only water, 300 mL per pot, following the method used by Arcoverde, Cortez, and Pereira (2018).

Functional characterization of seedling quality

Plant growth was evaluated by measuring plant height (cm) and stem diameter (cm) using a tape measure and digital caliper, respectively. Measurements were taken monthly over a period of 3 months. At the end of this period, the individuals were destructured for sample collection of their functional characteristics.

Evaluated functional characteristics included leaf number, dry and wet matter content of leaves, stems, and root system, as well as primary root length (PRL). The meaning and data acquisition procedures for each characteristic followed the protocol of Perez-Harguindeguy *et al.* (2013).

At the end of the experiment, the number of leaves of each individual was counted. To obtain the leaf dry matter content (LDMC) and stem dry matter content (SDMC), all leaves and the stem of the plant, from the first root to the first branch, respectively, were weighed. Weighing was done on a high-precision balance with four decimal places, measuring the saturated weight of water, and then the material was placed in an oven at 60°C for 72 h to obtain the dry weight. Both are expressed in $mg \cdot g^{-1}$, with dry weight (mg) divided by saturated water weight (g). The sum of LDMC and SDMC corresponds to the aboveground dry matter content (ADMC).

The roots were placed in a fine-mesh sieve (0.2 mm) and washed in running water to be studied after soil was also removed using a soft brush or fine tweezers. The depth of the root system was determined by the vertical length of the primary root from the surface to where the roots penetrated into the soil. Analysis of PRL was conducted using a tape measure, expressed in cm. Subsequently, to obtain saturated water weight (g), primary and secondary roots

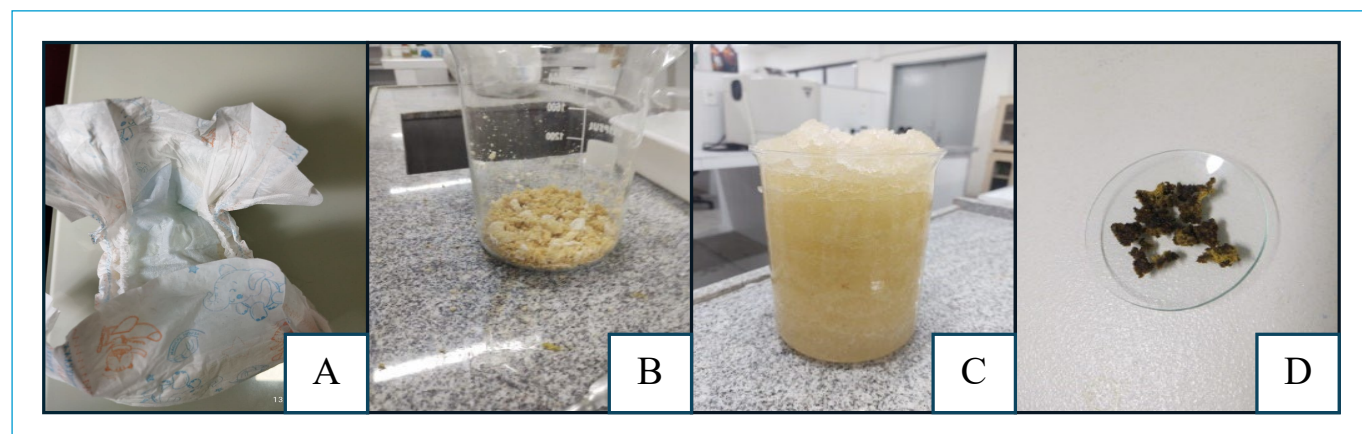


Figure 1 - Process of hydrogel extraction from disposable diapers: (A) disposable diaper, (B) extracted hydrogel, (C) washed hydrogel, (D) dried hydrogel.

were weighed while still moist. Immediately after this procedure, all roots were placed in an oven at 60°C for 72 h to obtain dry weight. The root dry matter content (RDMC) is the ratio of dry weight (mg) of the primary or secondary roots divided by saturated water weight (g), expressed in $\text{mg} \cdot \text{g}^{-1}$.

To analyze investment in seedling quality above and below ground, the Dickson Quality Index (DQI; DICKSON; LEAF; HOSNER, 1960) was calculated based on the height of the aboveground part (H), stem diameter at ground level (DGL, or DNS in Portuguese), and total dry matter content (TDMC, or TMST in the Portuguese acronym) of roots (RDMC, or TMSR in Portuguese) and the aboveground part (ADMC, or TMSPA in Portuguese). The index can be interpreted according to evidence presented by Gomes *et al.* (2002), where a higher index value indicates higher seedling quality.

Data analysis

To identify differences in functional characteristics and seedling quality among treatments and species, data were subjected to Shapiro–Wilk normality test and Bartlett’s homogeneity test. Data with normal distribution were compared using analysis of variance (ANOVA), followed by Scott–Knott test when ANOVA indicated significant differences among treatments at a significance level of 0.05. Non-normally distributed data were analyzed using the Kruskal–Wallis test, and if significant differences were found, means were compared using Mann–Whitney test. Statistical analyses were conducted using the software PAST (HAMMER; HARPER; RYAN, 2001).

RESULTS AND DISCUSSION

Water absorption

At 30 min, the polymer reaches its maximum water absorption capacity. After this time, the absorption values fluctuate but remain below the peak observed at 30 min (Figure 2). By 60 min, the material reaches a state of equilibrium, exhibiting alternating cycles of water absorption and release, a process attributed to osmosis. Swelling analysis revealed that the reused hydrogel absorbs 75 times

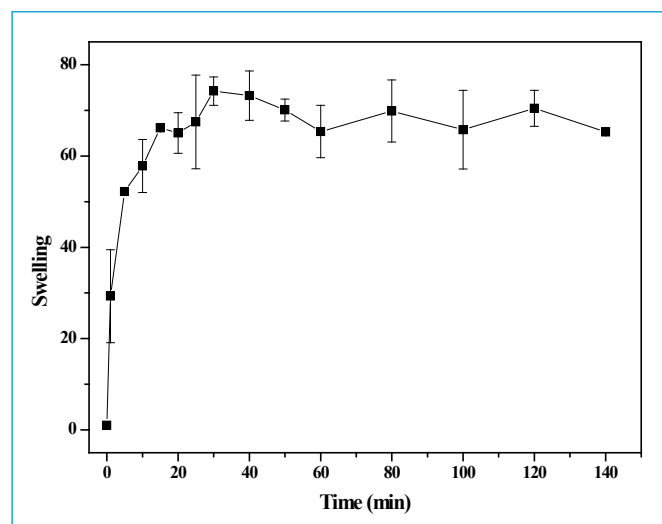


Figure 2 – Mean and standard deviation of the swelling kinetics for the hydrogel extracted from disposable diapers.

its dry weight in water. These findings indicate that the swelling indices are significantly high, demonstrating that the polymer is an exceptionally effective absorbent material. This high absorbent capacity justifies its application in disposable diapers (ZOHURIAAN-MEHR; KABIRI, 2008). Notably, even when reused, the hydrogel maintains its functional efficiency. Upon characterization, the hydrogel was successfully employed in seedling production by integrating it with the substrate (NOMURA *et al.*, 2019).

Height and diameter of the plants

Upon analysis of the results, it was observed that the hypothesis of the study was partially supported. Only individuals of *P. pyramidalis* showed significant differences in maximum height and diameter. The data for maximum height and diameter of *L. ferrea* and *M. caesalpinifolia* individuals did not differ among treatments (Table 1). Height and diameter data are commonly analyzed to determine plant quality (HAASE, 2008). Plants with greater height and diameter exhibit better post-planting performance and are suitable for environments with higher competition (CARGNELUTTI FILHO *et al.*, 2018).

Regarding the results of maximum height and diameter in this study, it was found that there were no significant differences among the treatments for individuals of *L. ferrea* and *M. caesalpinifolia*. This supports studies conducted by Deminski *et al.* (2024), whose research evaluated the use of hydrogel for soybean (*Glycine max* L.) crops, where no significant differences were observed in the total height of individuals, regardless of the hydrogel dosage used in the treatments. This study reinforces the findings of Cruz *et al.* (2024), who, when analyzing the influence of different hydrogel dosages on seedlings of *Abelmoschus esculentus* (L.) Moench (“quiabo”), found no significant differences in the “stem diameter” variable among the treatments.

However, it was expected that individuals would have greater height and diameter with the addition of hydrogel to the substrates, as studies have already been conducted evaluating these parameters with positive results, as seen in Carvalho *et al.* (2021); Mendes *et al.* (2022); and Endo, Schiebelbein, and Endo (2023), who assessed the effects of hydrogel on the height and diameter of *Sapindus saponaria* (“soapberry”), *Solanum lycopersicum* var. *cerasiforme* (“cherry tomato”), and *Anadenanthera colubrina* (Vell.) Brenan (“angico”) individuals, respectively.

However, differences were observed in individuals of *P. pyramidalis* (Table 1). The lowest maximum height was observed in individuals where irrigation was performed every 4 days and no hydrogel was added. In the mentioned treatment, the average height was 13.7 cm, which corresponds to 51.1% of the maximum height achieved in the treatment with hydrogel and daily irrigation (26.8 cm). This evidence corroborates studies by Klippel *et al.* (2014) on the impacts of water deficiency on the initial growth of *Eucalyptus urograndis* (eucalyptus), which identified that water deficit promotes a reduction in aboveground height, stem diameter, leaf area, and total dry matter of plants. On the other hand, the maximum diameter was higher in individuals that were irrigated daily, regardless of whether hydrogel was added or not. Individuals irrigated daily exhibited diameters that were 48.98% larger (with hydrogel) and 52.8% larger (without hydrogel) compared to treatments irrigated every 4 days. Similar results were found by Basilio *et al.* (2021), analyzing the establishment of grain sorghum (*Sorghum bicolor* L.) plants under different water regimes, where the authors observed that stem diameter was smaller in plants subjected to water deficit.

Table 1 – Means of height and diameter, in centimeter, of *L. ferrea*, *M. caesalpinifolia*, and *P. pyramidalis* individuals measured over three months.

		H-1	H-2	H-3/MH	Dia-1	Dia-2	Dia-3/MD
<i>L. ferrea</i>	CH_ID	20.8 ^c	62 ^b	107.2 ^{Aa}	1.76 ^b	3.62 ^a	4.78 ^{Aa}
	CH_I4D	16.4 ^c	54 ^b	90.4 ^{Aa}	1.80 ^c	3.46 ^b	5.02 ^{Aa}
	SH_ID	19.4 ^b	66.2 ^a	91 ^{Aa}	1.80 ^c	3.52 ^b	4.68 ^{Aa}
	SH_I4D	18.2 ^c	58 ^b	84.6 ^{Aa}	1.66 ^c	3.30 ^b	4.82 ^{Aa}
<i>M. caesalpinifolia</i>	CH_ID	11.8 ^c	36 ^b	68.2 ^{Aa}	0.92 ^c	3.36 ^b	5.64 ^{Aa}
	CH_I4D	9.4 ^b	22.6 ^b	31.2 ^{Aa}	0.94 ^c	2.84 ^b	3.94 ^{Aa}
	SH_ID	12.6 ^b	33.6 ^a	62 ^{Aa}	1.1 ^b	3.56 ^a	5.82 ^{Aa}
	SH_I4D	9.8 ^c	27.2 ^b	67.6 ^{Aa}	0.9 ^c	2.8 ^b	6.2 ^{Aa}
<i>P. pyramidalis</i>	CH_ID	12.2 ^b	17 ^a	26.8 ^{Aa}	2.22 ^b	3.24 ^a	4.9 ^{Aa}
	CH_I4D	7.9 ^c	11.8 ^b	17.6 ^{Aa}	1.54 ^b	1.82 ^b	2.4 ^{Ba}
	SH_ID	13.8 ^c	16.8 ^b	18.4 ^{Aa}	2.14 ^c	3.06 ^b	4.28 ^{Aa}
	SH_I4D	8.6 ^c	9.78 ^b	13.7 ^{Ba}	1.5 ^c	1.82 ^b	2.26 ^{Ba}

CH_ID: With hydrogel and daily irrigation; CH_I4D: With hydrogel and irrigation every 4 days; SH_ID: Without hydrogel and daily irrigation; SH_I4D: Without hydrogel and irrigation every 4 days; H_1: Height at 30 days; H_2: Height at 60 days; H_3: Height at 90 days; MH: Maximum height; DIA_1: Diameter at 30 days; DIA_2: Diameter at 60 days; DIA_3: Diameter at 90 days; MD: Maximum diameter. Superscript lowercase letters indicate statistical similarity for height and diameter over months within each treatment. Superscript uppercase letters indicate similarity of maximum height and diameter obtained for the species in different treatments.

Additionally, there was a significant difference in height and diameter among individuals of *L. ferrea*, *M. caesalpinifolia*, and *P. pyramidalis* across the treatments analyzed over time (Table 1). This occurs because hydrogel has the ability to mitigate the effects of water deficit, thereby influencing the growth of the evaluated seedlings (SILVA *et al.*, 2024). This result indicates that its use is important as it can reduce water stress that negatively affects plant growth (BRITO *et al.*, 2014).

Height data indicate that CH_ID, CH_I4D, and SH_I4D treatments with *L. ferrea* individuals showed a rapid increase. In contrast, the SH_ID treatment experienced a reduction in growth rate, with no statistical differences observed from the second to the third month after planting. Furthermore, diameter data showed that CH_I4D, SH_ID, and SH_I4D treatments had a significant increase over the months, while CH_ID treatment had a low growth rate, with no visible statistical differences. In this perspective, the reused hydrogel from disposable diapers becomes an effective measure, especially with irrigation occurring every 4 days. Since water is a fundamental and determining factor for plant development, and the lack of this resource affects seedling growth (BERNARDINO; BONOMO; SOUSA, 2019), the presence of hydrogel with longer irrigation intervals was beneficial for longer water retention.

The positive influence of increased water availability, as observed for *L. ferrea*, is consistent with studies on the use of commercial hydrogel conducted by Konzen *et al.* (2017). The authors noted that hydrogel promotes significant growth in height, diameter, and biomass of *Mimosa scabrella* Benth. seedlings (“bracatinga”), which is supported by Pinheiro *et al.* (2024), who found positive effects of hydrogel addition on height, diameter, and leaf number increase in “mamão papaya” (*Carica papaya* L.) seedlings. Similarly, Navroski *et al.* (2015) found that the use of hydrogel resulted in a significant increase in the height of *Eucalyptus dunnii* seedlings when compared to the absence of hydrogel.

Height results of *M. caesalpinifolia* individuals indicate that CH_ID and SH_I4D treatments showed a significant increase over the months, while CH_I4D and SH_ID treatments had a decrease in growth rate over time, contrary to expectations. Furthermore, diameter data indicate that CH_ID, CH_I4D,

and SH_I4D treatments had a progressive increase in diameter, whereas SH_ID treatment showed a reduction in diameter growth over time. The water stress imposed on the individuals caused the plants to grow more. This result may be linked to the fact that this species is native to the Caatinga, associated with arbuscular mycorrhizal fungi and nitrogen-fixing bacteria, thus adapted to the adverse conditions of the region, predominantly semi-arid climate (TAVARES *et al.*, 2012). The symbiotic association of the species with *Rhizobium* bacteria (CARVALHO, 2007) may mitigate the effects of water deficit and promote better development and growth of the plant species (MENDES; GARBEVA; RAAIJMARKERS, 2013).

From this finding, treatments involving hydrogel showed an increase in diameter over the months. Following the evidence presented by Nomura *et al.* (2019) in their study on the use of hydrogel for the production of “mamão papaya” (*C. papaya* L.) seedlings, a significant increase in diameter was observed with the implementation of hydrogel doses. Similar conditions were also found in *Handroanthus ochraceus* (Cham.) Mattos seedlings (“yellow ipê”) with the application of hydrogel and urea in the substrate, resulting in positive effects on the growth and quality of seedlings across different treatments, leading to increased height and diameter growth (MEWS *et al.*, 2015).

Height data of *P. pyramidalis* indicate that CH_I4D, SH_ID, and SH_I4D treatments showed a continuous increase in individuals, while CH_ID treatment had a reduction in growth rate over the months. Thus, it is evident that watering every 4 days is effective for the species, regardless of the presence of hydrogel. These results demonstrate that individuals of some species are resistant to stress and grow well even under soil water scarcity conditions (CADÊTE *et al.*, 2021). Diameter results show that SH_ID and SH_I4D treatments had a rapid increase in individual diameter, while CH_ID treatment had a decrease in the rate of diameter increase, and CH_I4D treatment had an increase in diameter growth from the first to the second month but a decrease in growth rate from the second to the third month—thus showing that, for the analyzed variable, there was no positive influence from hydrogel. This condition is consistent with findings by Oliveira *et al.* (2024), who did not encounter significant

effects on height and diameter growth for individuals of Jacarandá-da-Bahia (*Dalbergia nigra* (Vell.)) with the use of hydrotentative polymer. In this perspective, Monteiro *et al.* (2016), in their studies with 11 native Cerrado tree species, observed that the polymer did not show statistical significance for field growth and survival, as height and diameter variables may or may not be influenced by the presence of the polymer.

Biomass analysis in seedlings

From the obtained results, it was observed that the hypothesis of the study was partially supported, since there were significant differences in leaf number, dry matter content of secondary roots, and PRL for *L. ferrea* individuals (Table 2). Additionally, significant differences were found in the dry matter content of leaves and PRL for *M. caesalpiniaefolia* individuals, and differences in leaf number and LDMC were identified for *P. pyramidalis* individuals.

Regarding the number of leaves in *L. ferrea* individuals, CH_ID, CH_I4D treatments, as well as the SH_ID one, achieved the best results, showing a higher number of leaves. This occurs because water is a critical resource for plant development, and, in its absence, plants cannot complete their physiological processes, including photosynthesis, nutrient transport, and absorption (CAMPOS; SANTOS; NACARATH, 2021). Plants subjected to higher water concentrations produce more leaves (DUTRA *et al.*, 2012). The lack of this resource reduces cell turgor pressure and consequently restricts leaf elongation (RESENDE; HENDERSON; FERERES, 1981), contributing to decreased growth and production in plants.

Commercial hydrogel can mitigate the effects of water deficit (SILVA *et al.*, 2024). In this perspective, Nomura *et al.* (2019), analyzing different amounts of commercial hydrogel at a concentration of 3 g·L⁻¹, observed that *C. papaya* L. (papaya) seedlings had more leaves and longer roots. These results align with Pinto, Santana, and Godinho (2015), who experimented with commercial hydrogel and found it effective in producing Jalapeño pepper (*Capsicum annuum* L.) seedlings: Besides being a good water retainer, it also enhances biomass. This confirms that the use of hydrogel, whether commercial or recycled, has been an

effective alternative for biomass gain. In our study, increasing the interval between irrigations resulted in favorable outcomes only for the hydrogel-treated group.

For other analyzed characteristics of the species, differences were observed below ground. The dry matter content of secondary roots and the length of the primary root were greater when irrigation occurred every 4 days, regardless of hydrogel presence or absence. Individuals with hydrogel and irrigated every 4 days produced secondary roots with 44.26% more dry matter content and primary roots 26% larger compared to those irrigated daily. In the absence of hydrogel and with irrigation every 4 days, the individuals exhibited 32.44% more dry matter content and roots 13% larger. This is due to the plant's strategy to search for water. By extending the interval between irrigations and reducing water availability, plants invest more in characteristics that aid in water acquisition. Supporting evidence from Pezzopane *et al.* (2015) indicates that roots tend to develop toward areas of higher soil moisture under water-deficit conditions.

Regarding the results for individuals of *M. caesalpiniaefolia*, it is observed that there were significant differences in LDMC and PRL. Data for LDMC indicate that treatments with irrigation every 4 days resulted in better outcomes, i.e., greater increases in aboveground and belowground biomass. When irrigation occurred every 4 days, the plants grown in the presence of hydrogel showed a 21.3% increase in leaf dry matter, while in the absence of hydrogel, the increase was 11.5%. Some studies suggest that biomass parameters decrease under water restriction (CATUCHI *et al.*, 2012; VICIEDO *et al.*, 2019). However, our results differ from these studies, as they demonstrate that, under deficiency conditions, there was a greater increase in biomass in the analyzed plants. One possible explanation for this discrepancy could be that the species used has associations with nitrogen-fixing bacteria, thus minimizing the effects of water deficit and promoting better development of the plant species (MENDES; GARBEVA; RAAIJMARKERS, 2013).

Concerning PRL, it is noted that treatments with water restriction resulted in longer roots. Thus, the volume of soil explored and the intimate contact between root surfaces and soil are fundamental characteristics for effective water absorption by roots. This contact is enhanced by the emission of root

Table 2 - Functional characteristics collected from *L. ferrea*, *M. caesalpiniaefolia*, and *P. pyramidalis* individuals subjected to different treatments.

		Nf	DMCL	DMCPR	DMCSR	DMCW	RL	DQI
<i>L. ferrea</i>	CH_ID	29 ^a	0.3095 ^a	0.5763 ^a	0.1861 ^b	0.4879 ^a	13.4 ^b	1.11 ^a
	CH_I4D	34.6 ^a	0.3183 ^a	0.5289 ^a	0.3339 ^a	0.4701 ^a	18.1 ^a	1.02 ^a
	SH_ID	30.2 ^a	0.3245 ^a	0.5961 ^a	0.2085 ^b	0.5058 ^a	15.5 ^b	1.12 ^a
	SH_I4D	21.6 ^b	0.3166 ^a	0.4167 ^a	0.3086 ^a	0.4957 ^a	17.8 ^a	1.43 ^a
<i>M. caesalpiniaefolia</i>	CH_ID	16.4 ^a	0.2893 ^b	0.4262 ^a	0.1762 ^a	0.3845 ^a	13.4 ^b	1.24 ^b
	CH_I4D	15.4 ^a	0.3676 ^a	0.3700 ^a	0.1827 ^a	0.4384 ^a	25.5 ^b	1.65 ^a
	SH_ID	26 ^a	0.3417 ^b	0.3658 ^a	0.1709 ^a	0.3790 ^a	14.5 ^a	1.48 ^b
	SH_I4D	13 ^a	0.3863 ^a	0.4068 ^a	0.2428 ^a	0.3690 ^a	28.4 ^a	1.34 ^b
<i>P. pyramidalis</i>	CH_ID	12.4 ^a	0.1354 ^a	0.5765 ^a	0.3226 ^a	0.5426 ^a	16.2 ^a	1.07 ^a
	CH_I4D	6.4 ^b	1.8355 ^b	0.5545 ^a	0.2300 ^a	0.5178 ^a	17.2 ^a	3.54 ^a
	SH_ID	8.4 ^b	0.4581 ^b	0.4698 ^a	0.2974 ^a	0.7197 ^a	21.9 ^a	2.12 ^b
	SH_I4D	4.8 ^b	0.3709 ^b	0.5436 ^a	0.2783 ^a	0.4902 ^a	20.9 ^a	1.35 ^c

CH_ID: With hydrogel and daily irrigation; CH_I4D: With hydrogel and irrigation every 4 days; SH_ID: Without hydrogel and daily irrigation; SH_I4D: Without hydrogel and irrigation every 4 days; Nf: Number of leaves; DMCL: Dry matter content of leaves (mg·g⁻¹); DMCPR: Dry matter content of primary root (mg·g⁻¹); DMCSR: Dry matter content of secondary root (mg·g⁻¹); DMCW: Dry matter content of wood (mg·g⁻¹); RL: Root length (cm); DQI: Dickson Quality Index. Different superscript letters indicate statistical differences for each characteristic of the species across different treatments.

hairs; consequently, there is an increase in surface area and water absorption capacity (SANTOS; CARLESSO, 1998). Furthermore, in water scarcity situations, root expansion is greater due to the search for moist regions in deeper soil layers, as the surface tends to be drier in such conditions (PEZZOPANE *et al.*, 2015). In line with this perspective, similar results were found by Costa *et al.* (2023) when assessing the influence of water deficit on the production and quality of *Piptadenia moniliformis* Benth ("catanduva") seedlings. The authors observed that seedlings subjected to longer and more intense droughts showed greater increases in aboveground and belowground biomass compared to those irrigated daily. Based on this perspective, commercial hydrogel was tested for seedling production in *M. caesalpiniaefolia* individuals with different doses per total substrate volume, showing significant differences in leaf number and root length (ANTAS *et al.*, 2024).

Based on the results for individuals of *P. pyramidalis*, significant differences were identified in the number of leaves, indicating that the best results were shown by the CH_ID (Table 2). With the use of hydrogel and daily irrigation, the individuals showed 48.4% more leaves compared to when irrigation was performed every 4 days. When irrigated daily, individuals with hydrogel showed 32.3% more leaves than those without hydrogel. Similar results were obtained by Mendes *et al.* (2022) when analyzing the use of hydrogel under different water regimes for *Anadenanthera colubrina* (Vell.) Brenan. The authors found that hydrogel use resulted in higher increases in leaf number and height. This research aligns with studies by Carvalho *et al.* (2021), who observed positive responses in leaf number when using hydrogel in conjunction with water depths for individuals of *Sa. saponaria*. For LDMC, the CH_I4D treatment achieved higher values.

When it comes to the DQI, there was no difference between treatments for *L. ferrea* individuals. However, significant statistical differences were observed between treatments for individuals of *M. caesalpiniaefolia* and *P. pyramidalis*, with the highest index found in the CH_I4D treatment. According to Gomes *et al.* (2002), a higher index value indicates better seedling quality. Thus, irrigation every 4 days with the addition of hydrogel from disposable diapers favors the development of high-quality seedlings for both species.

Results by Silverio *et al.* (2024) differed from the present study, as they found lower fresh and dry masses of aboveground and root parts, as well as lower DQI values in *Eugenia myrcianthes* Nied. seedlings (wild peach) under stress conditions, regardless of hydrogel use. Additionally, Faller *et al.* (2020) noted that hydrogel use promotes growth in *Hymenaea courbaril* L. ("jatobá") seedlings for variables such as aboveground height (H), stem diameter (SD), DQI, and aboveground height/aboveground dry mass (H/AGDM). In another study on the use of commercial hydrogel for *Eucalyptus dunnii* Maiden subjected to different irrigation regimes, Felipe *et al.* (2020) observed that the hydrogel delays water-deficit symptoms, leading to enhanced plant development.

CONCLUSION

Thus, this study demonstrated the effectiveness of hydrogel from disposable diapers in producing high-quality seedlings of three native species from the Caatinga. The polymer was shown to help mitigate the effects of water deficit, with positive results depending on the species tested. Based on these findings, we conclude that studying the reuse of hydrogel from disposable diapers is important, as it provides similar benefits to commercial hydrogel in mitigating water stress and improving plant quality. However, future research is needed to evaluate the efficiency of different hydrogel dosages and their effects on other native species.

AUTHORS' CONTRIBUTIONS

Pereira, D.C.: Formal analysis, Investigation, Project administration, Software, Validation, Visualization, Writing—original draft, Writing—review and editing. Francisco, D.P.P.: Data curation, Formal analysis, Methodology. Magalhães Júnior, G.A.: Data curation, Investigation, Methodology, Writing—review and editing. Silva, M.A.M.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing.

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