Revista Ciência Agronômica, v. 52, n. 4, e20207560, 2021
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Seed germination of three species of Bignoniaceae trees under water stress[1]

Germinação de sementes de três espécies arbóreas da família Bignoniaceae sob estresse hídrico

Tamara Mariel Valdovinos[2]*, Rinaldo César de Paula[2], Patrícia Cândido da Cruz Silva[2], Gabriela Fanchini[2]

ABSTRACT - Seed germination and seedling development are strongly influenced by water availability and temperature, therefore, knowledge of the tolerance limits against these factors can generate subsidies to improve the multiplication and conservation strategies of native tree species. This study evaluates the effects of water stress on the germination of *Tabebuia roseoalba, Handroanthus chrysotrichus,* and *H. impetiginosus* seeds at two temperatures**.** Germination was performed on paper rolls moistened with polyethylene glycol (PEG 6000) solutions for the osmotic potentials of 0 (water); -0.05; -0.10; -0.15; -0.20; -0.30; -0.40; -0.60; -0.80 and -1.00 MPa. Germination tests were conducted at 25 and 30 °C, under 8 h photoperiod. Statistical analyses for each studied species followed a randomized complete block design, in a 2 × 10 split-plot scheme (plots - two temperatures and subplots – ten water potentials). The percentage of germination and normal seedlings, as well as the germination speed and synchronization indexes, were evaluated. The germination of *T. roseoalba, H. chrysotrichus,* and *H. impetiginosus* seeds decreased with increasing water deficit and at higher rates when associated with higher temperatures. The results demonstrate that the species sensitivity to water deficits induced by PEG 6000, increases with rising temperatures. *T. roseoalba* and *H. chrysotrichus* exhibited a germination tolerance range between -0.80 and -1.00 MPa. Furthermore*, H. impetiginosus* is more sensitive and displayed a tolerance range between -0.60 and -0.80 MPa.

Key words: *Handroanthus.* Osmotic potential. *Tabebuia.* Temperature.

RESUMO - A água e a temperatura influenciam na germinação de sementes e no desenvolvimento de plântulas. O conhecimento dos limites de tolerância frente a estes fatores, pode gerar subsídios para melhorar as estratégias de multiplicação e conservação das espécies arbóreas nativas. Objetivou-se avaliar os efeitos do estresse hídrico na germinação de sementes de *Tabebuia roseoalba, Handroanthus chrysotrichus* e *H. impetiginosus* sob duas temperaturas. A germinação foi realizada em rolos de papel, umedecidos com soluções aquosas de polietilenoglicol (PEG 6000) nos potenciais hídricos de 0 (água); -0,05; -0,10; -0,15; -0,20; -0,30; -0,40; -0,60; -0,80 e -1,00 MPa. Os testes de germinação foram conduzidos a 25 e 30 °C, sob fotoperíodo de 8 h. As análises estatísticas foram realizadas separadamente por espécie, segundo o delineamento experimental de blocos casualizados, em esquema de parcelas subdivididas 2 × 10 (duas temperaturas nas parcelas e dez potenciais hídricos nas subparcelas). Avaliou-se a porcentagem de germinação e de plântulas normais, e os índices de velocidade e de sincronização da germinação. A germinação de sementes de *T. roseoalba*, *H. chrysotrichus* e *H. impetiginosus* diminui com o aumento do déficit hídrico e em maior proporção, quando esse está associado a temperaturas mais elevadas, demonstrando que a sensibilidade das espécies frente ao estresse hídrico induzido por PEG 6000, aumenta com a elevação da temperatura. A faixa limite de tolerância para a germinação de sementes de *T. roseoalba* e *H. chrysotrichus* se situa entre -0,80 e -1,00 MPa; *H. impetiginosus* é mais sensível, com limite de tolerância entre -0,60 e -0,80 MPa.

Palavras-chave: *Handroanthus.* Potencial osmótico. *Tabebuia.* Temperatura.

DOI: 10.5935/1806-6690.20210072
Editor-in-Chief: Prof. Alek Sandro Dutra - alekdutra@ufc.br
*Author for correspondence
Received for publication 09/10/2020; approved on 25/03/2021

[1] This research was financed by CAPES and the manuscript is part of the thesis submitted by the first author to the School of Veterinary and Agrarian Sciences, São Paulo State University (Unesp)

[2] Department of Agricultural Production Sciences, School of Veterinary and Agrarian Sciences, São Paulo State University/Unesp, Jaboticabal, SP, Brazil. ta.mariel@hotmail.com (ORCID ID 0000-0001-9132-4753), rinaldo.paula@unesp.br (ORCID ID 0000-0001-9088-3924), patriciacandidocs@gmail.com (ORCID ID 0000-0002-3555-5706), gabriela.franchini@unesp.br (ORCID ID 0000-0001-6632-6167)

INTRODUCTION

Bignoniaceae Juss comprises 840 species and 82 genera (LOHMANN, 2018). In Brazil, *Handroanthus* Mattos is represented by 27 species and *Tabebuia* Gomes ex DC by 15 species. These are trees and shrubs, naturally occurring in the Brazilian phytogeographic domains of the Amazonia, Caatinga, Cerrado, Atlantic Forest, and Pantanal (LOHMANN, 2010). All these tree species, popularly known as ipe, including *Tabebuia roseoalba* (Ridl.) Sandwith (white ipe), *Handroanthus chrysotrichus* (Mart. ex DC.) Mattos (yellow ipe), and *H. impetiginosus* (Mart. ex DC.) Mattos (purple ipe), have ornamental, medicinal, and lumber value. The trees stand out for their exuberance during flowering and are commonly used in urban afforestation, in addition to being recommended for reforestation and restoration of degraded areas (LORENZI, 2008). These species annually produce a large amount of light, winged seeds, spread by the wind, but with few reserves and a short viability period under natural conditions (MELLO; EIRA, 1995).

During germination, water absorption by the seeds leads to tissue rehydration, the intensification of the respiratory process and other metabolic pathways, resulting in the development of the embryonic axis. Temperature interferes with water absorption dynamics by regulating the speed at which water passes through the seminal integument and cell membranes, limiting the speed of biochemical reactions, and with the physiological processes that determine germination as well (CARVALHO; NAKAGAWA, 2012). Water absorption by the seeds is impaired in very negative water potentials and the water deficit reduces the germination percentage and speed, especially at the beginning of imbibition (BOTELHO; PEREZ, 2001). Each species has a minimum water potential, below which germination is suppressed, and it is called the maximum limit to drought tolerance (HARTMANN *et al.*, 2011; KAPPES *et al.*, 2010).

The capacity to germinate under several environmental factors is a fundamental aspect for the survival of plant species, since species are more sensitive in this developmental stage, resulting in higher mortality (HARTMANN *et al*., 2011). In this context, water scarcity combined with higher temperatures may compromise the regeneration and perpetuation of some species in the natural environment. Thus, even within the temperature range considered optimal for seed germination of a given species, the germination process may behave differently in the presence of stressful factors, such as water deficit. It is also likely that the loss of plant species caused by ongoing climate change does not occur randomly, because the possible extinction of species depends on their vulnerability to the new climatic conditions (GARCÍA-VALDÉS; BUGMANN; MORIN, 2018) resulting, in general, from the combined occurrence of simultaneous stress factors.

Studies related to the germination response of seeds under artificial stress conditions are tools that allow assessing parameters such as tolerance, survival, and adaptation limits of species to natural stress conditions (GUEDES *et al*., 2013). The knowledge of tolerance limits against abiotic factors, such as water availability and its interaction with temperature, may generate subsidies to optimize the multiplication and conservation strategies of native species.

The objective of this work is to evaluate the effects of water stress associated with two temperatures considered optimal, on seed germination and seedling performance of *Tabebuia roseoalba*, *Handroanthus chrysotrichus* and *H. impetiginosus*, to determine the species tolerance range to drought, assuming that both germination capacity and seedling development can be used as tolerance criteria for the different abiotic factors.

MATERIAL AND METHODS

Seeds of *Tabebuia roseoalba*, *Handroanthus chrysotrichus* and *H. impetiginosus* were collected from mother trees in Jaboticabal, SP, a town in the Central-Northern region of the state of São Paulo, Brazil (21º 15’ 22” S, 48º 18’ 58” W, with altitude ranging from 465 to 685 m). The regional climate is classified as Cwa-subtropical, with dry winter, according to Köppen (GREGGIO; PISSARRA; RODRIGUES, 2009). The region has two well-defined seasons: a rainy period with excess precipitation, from October to March, and a dry one, with a marked water deficit, from April to September (ANDRÉ; GARCIA, 2014) with monthly average temperatures ranging between 18.8 and 24.3 °C (GARCIA; ANDRÉ, 2015). Tropical broadleaved forest and stretches of Cerrado originally constituted the dominant vegetation cover of this region (GREGGIO; PISSARRA; RODRIGUES, 2009).

Ripe fruits of the three species at the beginning of natural dehiscence, showing the first cracks/openings, but without seed dispersal were collected in the second half of September 2017, and registered in the National System of Genetic Resources (SisGen) under numbers A2AA3D2 and A52BDCE. The fruits were then submitted to a natural drying process that lasted between 10 and 15 days, according to species. After that, the seeds were extracted and processed manually, placed in Kraft paper bags, and stored in an air-conditioned room (16.5 ºC and 50% R. H.) until the beginning of the germination tests.

Seed moisture content was determined by the greenhouse method at 105 ± 3 °C for 24 hours (BRASIL, 2013), using four repetitions of 25 seeds. Before the germination tests, seed surfaces were sterilized with 1% sodium hypochlorite for 2 minutes, using a commercial solution with 2.5% active principle, and then washed with distilled water for 30 seconds (BRASIL, 2013).

The experiments were carried out in randomized blocks, in a split-plot scheme, with two temperatures in the plots and 10 water potentials in the subplots. To submit the seeds to water stress at 25 and 30 ºC, aqueous solutions of polyethylene glycol (PEG 6000) were prepared according to Villela, Doni Filho and Sequeira (1991) to obtain the following water potentials (P): 0 (distilled water), -0.05, -0.10, -0.15, -0.20, -0.30, -0.40, -0.60, -0.80 and -1.00 MPa.

For each species, 100 seeds per treatment were divided into five replicates of 20 seeds each that were distributed on two paper towel sheets, covered with a third sheet, and rolled over. The paper towel was moistened with distilled water (control) or with PEG 6000 solutions, in an amount equivalent to 2.5 times the mass of the non-hydrated paper (BRASIL, 2013). The rolls were packaged in transparent plastic bags to reduce water loss through evaporation. The germination tests were carried out in Biochemical Oxygen Demand (B.O.D.) germinators set at 25 and 30 °C accordingly, with a photoperiod of eight hours, using daylight fluorescent lamps (4 x 20 W). Although Brazil (2013) recommends 25 °C for the germination test of these three species, the two temperatures were chosen based on preliminary tests (data not shown) that indicated these two temperatures are within the range considered optimal for seed germination of the studied species (BRANCALION; NOVEMBRE; RODRIGUES, 2010; SANTOS; SUGAHARA; TAKAKI, 2005).

After the tests were installed, the germinated seeds, considered as those with a primary root emission of at least 0.5 cm, were counted daily for 21 days. At the end of the experiment, the following traits were determined:

1) germination percentage (G%) – defined as the percentage ratio between the number of seeds with primary root protrusion and the total seeds;

2) percentage of normal seedlings (NS%) - the percentage ratio between the number of seedlings with perfect essential structures and the total seeds;

3) germination speed index (GSI) – obtained from the daily number of germinated seeds, according to the formula proposed by Maguire (1962):

$$IVG = G_1/N_1 + G_2/N_2 + ... + G_n/N_n$$

Where: G_1, G_2, G_n = number of seeds germinated in the first, second, and last counts;

N_1, N_2, N_n = number of days between the sowing and the first, second and last counts.

4) synchronization or uncertainty index (SI) – given by the following equation and expressed in bits (units of information), according to Labouriau (1983):

$$IS = -\sum_{i=1}^{K} fi.\log_2(fi) \cdots With \cdots fi = \frac{ni}{\sum_{i=1}^{K} ni}$$

Where fi: relative frequency of germination;

k: last day of observation;

ni: number of seeds germinated on the day i.

Statistical analyses were performed separately per studied species. Data were submitted to analysis of variance and regression ($p \leq 0.05$), using polynomial regression models and a non-linear logistic model (logistics 1), as presented by Azerêdo, Paula and Valeri (2016):

$$y = a/(1 + e^{-k(x-xc)})$$

Where:

y= trait value for a given value of x (water potential);

a = maximum value of trait y;

k = relative growth rate (in the present case of reducing y);

xc = value of x (water potential) that decreases the trait maximum value by 50%.

RESULTS AND DISCUSSION

Before the beginning of the experiments, the seed moisture contents were 8.3, 9.8 and 6.8% for *Tabebuia roseoalba*, *Handroanthus chrysotrichus*, and *H. impetiginosus*, respectively.

A significant temperature × water potential interaction was observed for the germination percentage (G) in *Tabebuia roseoalba* and *Handroanthus chrysotrichus*, percentage of normal seedlings (NS) in *T. roseoalba* and *H. impetiginosus*, and germination speed index (GSI) in all three species. It is highlighted the different responses of the studied species to the temperature and water potential combination during the germination process. The water potential either by itself or combined with temperature affected the evaluated traits in all three species. The germination synchronization index (SI) showed a significant isolated effect of both water potential and temperature in all three species, a similar result was observed for normal seedlings of *H. chrysotrichus*. The germination percentage of *H. impetiginosus* was significantly affected by the water potential only. Temperature affected the synchronization index and normal seedlings in all three species; germination in *T. roseoalba* and *H. chrysotrichus*, and the germination speed index in *T. roseoalba* (Table 1).

For all three species, the percentage of germination and normal seedlings and the germination speed index decreased as the water potential became more negative, regardless of the temperature (Figures 1-3).

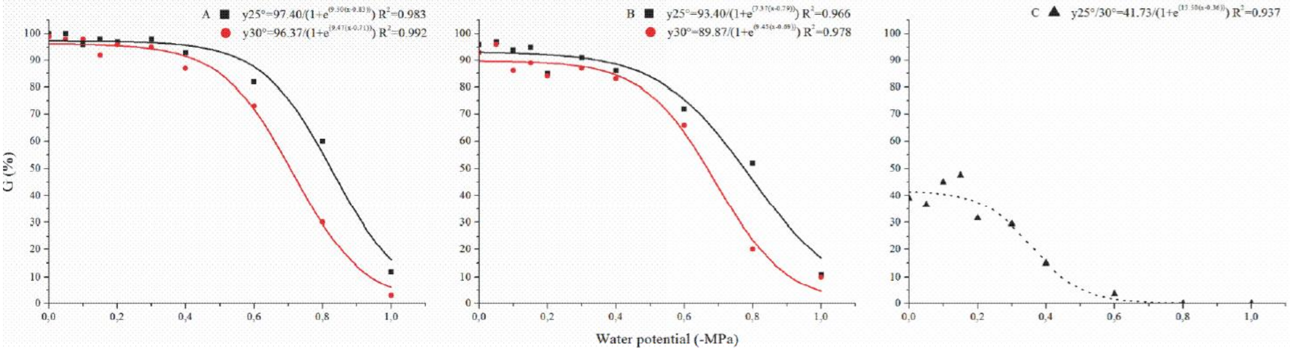
Tabebuia roseoalba seeds exhibited a germination percentage above 70% up to -0.6 MPa water potential for both temperatures (Figure 1A). The germination of *H. chrysotrichus* seeds was greater than 70% up to -0.6 MPa at 25 °C (Figure 1B). Further, lower germination values were obtained for both species in all water potentials at 30 °C. The maximum germination values of *Tabebuia roseoalba* and *Handroanthus chrysotrichus* seeds decreased by 50% for -0.83 and -0.79 MPa at 25 °C and -0.71 and - 0.69 MPa at 30 °C, respectively. Therefore, it is observed that the negative effects of water stress were potentiated at higher temperatures. For *H. impetiginosus* (Figure 1C) the water potential × temperature interaction was not significant, but there was an isolated effect of water potential. Compared to the other two species, *H. impetiginosus* had lower germination rates (less than 50%) and less tolerance to water stress; the maximum germination values decreased by 50% at -0.36 MPa while a sharp reduction was observed at -0,60 MPa.

Table 1 - Summary of the analysis of variance for germination percentage (G), percentage of normal seedlings (NS), germination speed index (GSI) and synchronization index (SI), obtained for *Tabebuia roseoalba*, *Handroanthus chrysotrichus*, and *Handroanthus impetiginosus* seeds submitted to different water potentials induced by polyethylene glycol (PEG 6000) at 25 and 30 °C

Traits/ parameters	F values			Mean	CV1 (%)	CV2 (%)
	Temperature (T)	Water potential (P)	Interaction (TxP)			
			Tabebuia roseoalba			
G (%)	5.34^{+}	83.64**	1.82^{+}	80.00	17.35	13.14
NS (%)	21.39**	116.10**	2.24*	66.00	12.07	14.05
GSI	20.08**	78.90**	2.64**	5.00	29.98	20.07
SI (bits)	16.94*	7.47**	1.16^{ns}	1.18	37.59	39.68
			Handroanthus chrysotrichus			
G (%)	6.50^{+}	77.53**	2.01*	75.00	17.08	13.84
NS (%)	22.85**	91.84**	1.33^{ns}	54.00	20.25	18.88
GSI	3.95^{ns}	126.73**	4.66**	2.33	40.83	16.25
SI (bits)	16.09*	7.88*	0.43^{ns}	1.45	24.07	31.30
			Handroanthus impetiginosus			
G (%)	1.13^{ns}	45.13**	1.58^{ns}	25.00	43.75	35.35
NS (%)	5.81^{+}	48.50**	1.80*	13.00	49.09	44.30
GSI	6.52^{ns}	45.82**	2.03*	0.59	33.4	37.69
SI (bits)	11.74*	50.45**	0.97^{ns}	1.17	21.07	31.69

**,* and + = Significant at 0.01, 0.05 and 0.10 by the F test, respectively; ^{ns} = non-significant at 5%; CV^1 - coefficient of variation within plots; CV^2 - coefficient of variation within subplots

Figure 1 - Germination percentage (G, %) obtained for *Tabebuia roseoalba* (A), *Handroanthus chrysotrichus* (B) and *Handroanthus impetiginosus* (C) seeds submitted to different water potentials simulated with polyethylene glycol (PEG 6000), at 25 and 30 °C



For *T. roseoalba*, normal seedling percentages (NS) above 75% were recorded up to -0.30 and -0.40 MPa osmotic potential at 30 and 25 °C, respectively (Figure 2A). The maximum normal seedling percentages decreased by 50% for -0.69 and -0.53 MPa at 25 and 30 °C, respectively, proving the severe effect of the water deficit associated with higher temperature (30 °C). The difference between the two temperatures was evident from -0.15 MPa, becoming more accentuated at -0.80 MPa, whereas no normal seedlings were formed at -1.00 MPa in either temperature.

For *H. chrysotrichus*, the normal seedling percentages (Figures 2B) were not significantly different for the studied water potentials at both temperatures; however, at -0.50 MPa, there is evidence that normal seedling percentages decreased 50% in relation to the maximum value verified at 0 MPa. The more negative the water potentials became the more drastic was the reduction of normal seedling percentages, with no normal seedling formed at -1.00 MPa, indicating total seed sensitivity to this stress level.

For *H. impetiginosus*, the normal seedling percentages (Figure 2C) were as low as 35% and 27% at 30 and 25 ºC, respectively, even at 0 MPa. Furthermore, maximum values of normal seedlings decreased by 50% for -0.21 and -0.12 MPa water potentials at 25 and 30 °C, respectively, showing that the 30 °C temperature was more harmful to the formation of normal seedlings than 25 °C. Very few normal seedlings (less than 15%) were formed up to -0.30 MPa, for both temperatures and, after that, there was total seed sensitivity to water stress (Figure 2C). Abnormal seedlings were observed, especially with albinism, seedlings without the main root, and also with deformed or incomplete shoots, thus explaining the lower percentage of normal seedlings of *Handroanthus impetiginosus* compared to the two other species.

The *Handroanthus impetiginosus* seeds presented a lower germination speed index (GSI) compared to *Tabebuia roseoalba* and *H. chrysotrichus* (Figure 3). The three species studied behaved similarly regarding GSI, which decreased with the decreasing water potential, regardless of temperature. However, the germination process was more accelerated at 30 °C, but as the water deficit increased, the differences between the germination speed indices determined for the two temperatures also decreased. GSI became practically the same from -0.60 MPa in *Tabebuia roseoalba* (Figure 3A), -0.40 MPa in *Handroanthus chrysotrichus* (Figure 3B), and -0.20 MPa in *Handroanthus impetiginosus* (Figure 3C), thus reinforcing the potency of the water deficit effect at 30 °C.

Figure 2 - Percentage of normal seedlings (NS, %) obtained for *Tabebuia roseoalba* (A), *Handroanthus chrysotrichus* (B), and *Handroanthus impetiginosus* (C) seeds submitted to different water potentials simulated with polyethylene glycol (PEG 6000), at 25 and 30 °C.

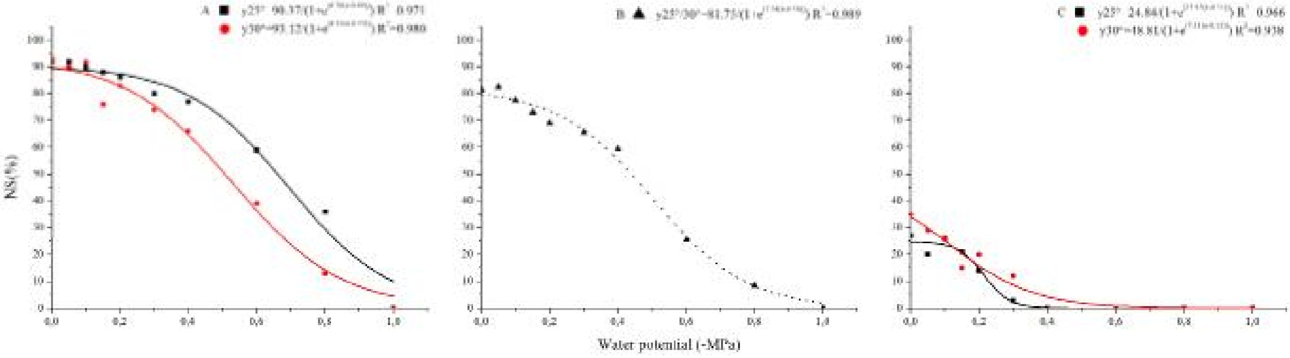
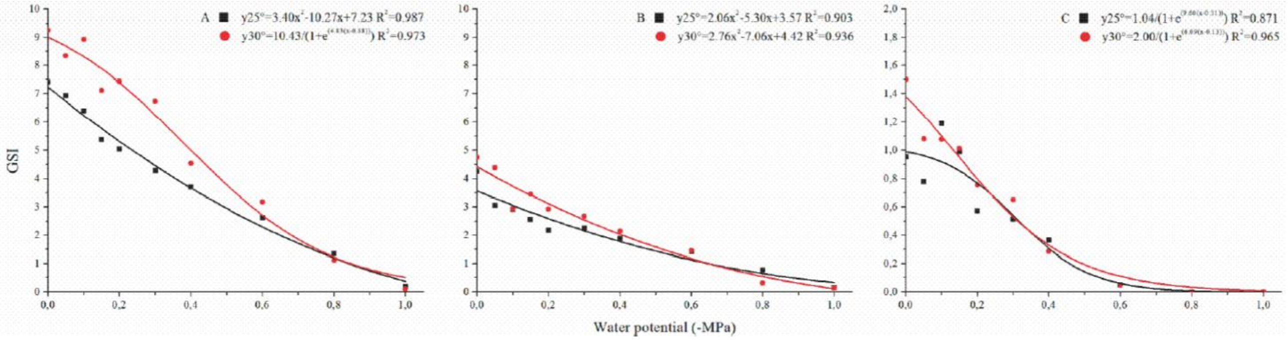


Figure 3 - Germination speed index (GSI) obtained from *Tabebuia roseoalba* (A), *Handroanthus chrysotrichus* (B), and *Handroanthus impetiginosus* (C) seeds submitted to different water potentials simulated with polyethylene glycol (PEG 6000), at 25 and 30 °C.



The synchronization index (SI), or information entropy, of the germination process increased for *Tabebuia roseoalba* and *Handroanthus chrysotrichus* seeds up to -0.60 MPa, indicating that the decreasing water availability in the substrate changed the seed germination synchrony, increasing the entropy. From -0.80 MPa, average SI (Figures 4A and 4B) decreased as a result of the smaller number of seeds that germinated under severe water stress conditions, where only seeds with greater vigor within the lot manage to germinate.

For *Handroanthus impetiginosus*, the SI peaked in the water potentials that did not affect germination (0; -0.05; -0.10; -0.15 and -0.20 MPa) and decreased 50% from the maximum value, at -0.43 MPa. Therefore, the uneven germination was maintained down to -0.30 MPa (Figure 4C), since from that point onwards, germination was compromised under more negative water potentials. Contrary to the results observed for *H. impetiginosus*, *Tabebuia roseoalba* and *H. chrysotrichus* seeds maintained greater germination synchronicity, under the most ideal conditions for germination, when sufficient water for imbibition was available (control treatment: 0 MPa, Figures 4A and 4B).

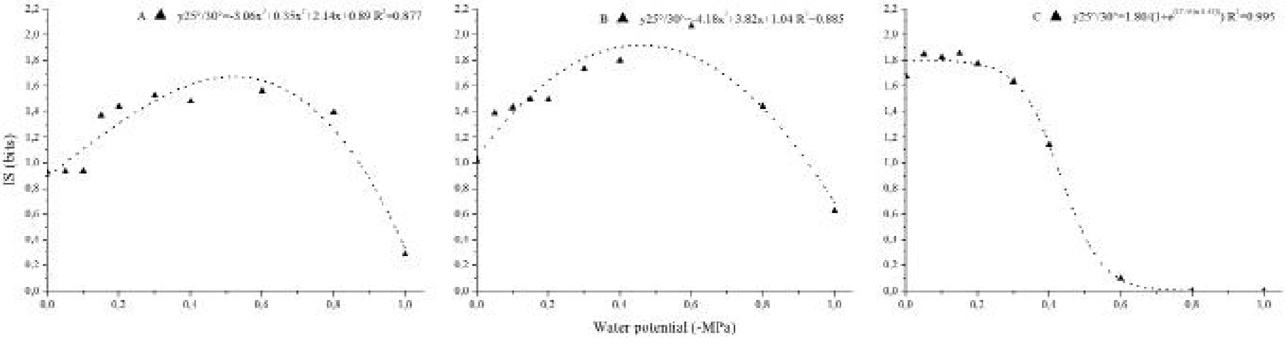
The results of this study show that water stress negatively affected the germination and development of *Tabebuia roseoalba*, *Handroanthus chrysotrichus* and *H. impetiginosus* seedlings, and also changed seed germination synchronicity. In general, when the water potential of the solution is lower than that of the embryo's cells, germination speed and percentage, as well as seedling formation, decrease, as water deficit affects cell elongation and wall synthesis (OAK; NAKAGAWA, 2012).

The seeds of the three species showed greater sensitivity to water deficit associated with higher temperature (30 °C) so that as the water deficit became more severe, the tolerance limit was lower at 30 °C compared to 25 °C. Therefore, the combination of water deficit and higher temperatures reduced markedly the seed germination and seedling performance, even for temperatures within the range considered optimal for most tropical tree species (BRANCALION; NOVEMBRE; RODRIGUES, 2010). For example, the 20 to 30 °C temperature range has been deemed optimal for the germination of *Tabebuia chrysotricha* (Mart. ex DC.) Standl and *Tabebuia roseoalba* (SANTOS; SUGAHARA; TAKAKI, 2005).

Comparing drought tolerance limits, *Handroanthus impetiginosus* is more sensitive to water deficit. The tolerance limit for the germination of *Tabebuia roseoalba* and *Handroanthus chrysotrichus* seeds under water deficit was between -0.80 and -1.00 MPa, while for *H. impetiginosus* between -0.60 and -0.80 MPa. It is noteworthy that the germination of *H. impetiginosus* seeds was totally inhibited at -0.80 MPa. For *T. roseoalba* and *H. chrysotrichus*, no normal seedlings were formed at -1.00 MPa, although germination was observed considering the primary root protrusion.

The tolerance limits of -0.80 and -1.00 MPa, observed for *Tabebuia roseoalba* and *Handroanthus chrysotrichus*, coincide with those observed for *Anadenanthera colubrina* (Vell.) (Fabaceae) (DUARTE *et al*., 2018). Certain forest species are more sensitive to water stress, such as *Chorisia glaziovii* (Bombacaceae) whose germination was totally inhibited at -0.30 MPa of PEG 6000 (SILVA *et al*., 2016). Others, such as *Peltophorum dubium* Spreng (Taubert) (Fabaceae), are resistant to water stress simulated with PEG 6000, with a tolerance limit between -1.4 and -1.6 MPa (BOTELHO; PEREZ, 2001). Avrella *et al.* (2017) report that the *Mimosa scabrella* Benth germination became null at -0.60 MPa using the PEG 6000 to simulate water stress. However, according to the authors, it is a promising species for cultivation in soils with water stress since germination and seedling formation occurred satisfactorily in the osmotic potentials normally observed in the soils usually planted with this species.

Figure 4 - Synchronization index (SI, bits) obtained from *Tabebuia roseoalba* (A), *Handroanthus chrysotrichus* (B), and *Handroanthus impetiginosus* (C) seeds submitted to different water potentials simulated with polyethylene glycol (PEG 6000), at 25 and 30 °C



Although the tolerance limits are specific for each species, there are differences when comparing the results obtained with those of other studies, such as Marques *et al.* (2004) with *Handroanthus chrysotrichus* and Santos *et al.* (2018) with *Handroanthus impetiginosus*. It is likely that genetic variability (different mother trees sampled), the origin of mother trees (individuals adapted to different climatic conditions), and also different environmental causes, can change the physiological quality of seed lots, which would explain the intraspecific differences observed regarding the tolerance to water stress trait.

The germination speed indices were higher for all three species studied at 30 °C. Guedes *et al.* (2013) reported the same behavior for *Apeiba tibourbou* seeds, a forest species belonging to the Tiliaceae family. The authors attributed this to the possibly faster imbibition and, consequently, to the acceleration of metabolic reactions that occurred during the germination process in the higher temperature (30 °C). However, the increase in temperature intensified the effects of the PEG 6000-induced water stress on the germination speed of the three species, corroborating the result observed by Santos *et al.* (2018).

Considering the percent values of germination and normal seedlings of the three species, water stress was more harmful to the formation of normal seedlings than to seed germination. Also, the germination speed was not based on normal seedlings, but rather on seeds that emitted primary root whose subsequent root system did not develop in more negative potentials, favoring deterioration and preventing the formation of normal seedlings.

In this research, regardless of species and temperature, water stress also affected the synchronicity of seed germination. Likewise, lack of synchronization was observed for *Amphilophium crucigerum* (Bignoniaceae), in which the greater entropy of the germination process causes germination to spread over time, allowing the seeds to find, at some point, more adequate conditions for the seedling survival in ecosystems whose environmental conditions change periodically (RIBEIRO; PEREIRA; OLIVEIRA, 2017). On the contrary, lower synchronization indices indicate that the system is more orderly, providing higher values of germination percentage and speed, which occurs at the optimal germination temperature (SANTOS; SUGAHARA; TAKAKI, 2005).

For germination to occur, seeds must reach a minimum water content, which varies among species and takes longer to be reached when the substrate water potential is lower (GUEDES *et al*., 2013). Very fast germinating species generally have small seeds, with few reserves and have thin, soft integuments that absorb water quickly (PARSONS, 2012). *Tabebuia roseoalba* and *Handroanthus chrysotrichus* showed greater synchronicity and germination speed, especially under optimal conditions, therefore, their traits facilitate the dispersal and rapid establishment of seedlings since the small reserve of their seeds implies a short period of viability (SANTOS; SUGAHARA; TAKAKI, 2005).

Comparatively, *Handroanthus impetiginosus* showed slow and asynchronous germination, even when water sufficed. This behavior probably contributes to reduce or avoid the risk of seedling mortality, which is imposed by very fast and synchronized germination, especially in regions with seasonal droughts. For this species, Martins *et al*. (2015) found that delayed germination, as well as strong osmotic inhibition, contribute to delay the emergence of seeds in the soil and, therefore, constitute mechanisms to avoid stress; a strategy that was conserved during evolution, and guarantees adaptive value in an environment where precipitation is less predictable. Furthermore, the ability to form adventitious roots from the hypocotyl after dehydration and the reestablishment of post-germination tolerance (induced after osmotic treatment of germinated seeds with radicles up to 3 mm long) are additional mechanisms of adaptation to the seasonal droughts observed in biomes such as the Cerrado and Caatinga, where *H. impetiginosus* inhabits, thus favoring the survival of seedlings under selective pressure (VIEIRA *et al*., 2010).

Based on the results of this research, the *Handroanthus impetiguinosus* seeds have longer germination, disorganized over time, while needing simultaneously higher levels of hydration to activate germination. Comparatively, *Tabebuia roseoalba* and *H. chrysotrichus* seeds germinate faster, more synchronously, and show greater tolerance to low water availability. Although different climatic conditions can favor the occurrence of different strategies for tolerance and survival of seeds and seedlings (MARTINS *et al*., 2015), it is of fundamental importance to understand how environmental factors, such as water availability, affect seed germination and, thus, better understand the ecological behavior of species in a natural environment (ANTUNES *et al*., 2011). Thus, this research contributes to the understanding of the regeneration strategies of the studied species and how varying temperature and water availability may affect them; this information is highly important for establishing management practices to successfully restore degraded tropical forests.

CONCLUSIONS

1. The percentages of germinated seeds of *Tabebuia roseoalba*, *Handroanthus chrysotrichus* and *H.*

impetiginosus decrease faster when water deficit is associated with higher temperatures, demonstrating that the species sensitivity to water stress increases with increasing temperature.

2. The range of tolerance to water deficit during germination of *Tabebuia roseoalba* and *Handroanthus chrysotrichus* seeds is between -0.80 and -1.00 MPa, while for *H. impetiginosus* is between -0.60 and -0.80 MPa. Thus, *T. roseoalba* and *H. chrysotrichus* are more tolerant to water stress than *H. impetiginosus*.

ACKNOWLEDGMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

REFERENCES

ANDRÉ, R. G. B.; GARCIA, A. Variabilidade temporal da precipitação em Jaboticabal – SP. **Nucleus**, v. 11, n. 2, p. 397-402, 2014.

ANTUNES, C. G. C. *et al.* Germinação de sementes de *Caesalpinia pyramidalis* Tul. (Catingueira) submetidas a de ciência hídrica. **Revista Árvore**, v. 35, n. 5, p. 1007-1015, 2011.

AVRELLA, E. D. *et al.* Estresse hídrico e salinidade na germinação de sementes de Mimosa scabrella Benth. **Revista Espacios**, v. 38, n. 47, p. 24-34, 2017.

AZERÊDO, G. A.; PAULA, R. C.; VALERI, S. V. Germinação de sementes de *Piptadenia moniliformis Benth.* sob estresse hídrico. **Ciência Florestal**, v. 26, n. 1, p. 193-202, 2016.

BOTELHO, B. A.; PEREZ, S. C. J. G. A. Estresse hídrico e reguladores de crescimento na germinação de sementes de canafístula. **Scientia Agrícola**, v. 58, n. 1, p. 43-49, 2001.

BRANCALION, P. H. S.; NOVEMBRE, A. D. D. L. C.; RODRIGUES, R. R. Temperatura ótima de germinação de sementes de espécies arbóreas brasileiras. **Revista Brasileira de Sementes**, v. 32, n. 4, p. 15-21, 2010.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Instruções para análise de sementes de espécies florestais**. Brasília: MAPA, 2013. 98 p.

CARVALHO, N. M.; NAKAGAWA, J. **Sementes**: ciência, tecnologia e produção. 5. ed. Jaboticabal: FUNEP, 2012. 590 p.

DUARTE, M. M. *et al.* Influência do estresse hídrico na germinação de sementes e formação de plântulas de angico branco. **Advances in Forestry Science**, v. 5, n. 3, p. 375-379, 2018.

GARCIA, A.; ANDRÉ, R. G. B. Variabilidade temporal da temperatura do ar em Jaboticabal – SP. **Nucleus**, v. 12 n. 1, p. 181-188, 2015.

GARCÍA-VALDÉS, R.; BUGMANN, H.; MORIN, X. Climate change-driven extinctions of tree species affect forest functioning more than random extinctions. **Diversity and Distribuitions**, v. 24, n. 7, p. 906-918, 2018.

GREGGIO, T. C.; PISSARRA, T. C. T.; RODRIGUES, F. M. Avaliação dos fragmentos florestais do município de Jaboticabal-SP. **Revista Árvore**, v. 33, n. 1, p. 117-124, 2009.

GUEDES, R. S. *et al.* Germinação e vigor de sementes de *Apeiba tibourbou* submetidas ao estresse hídrico e diferentes temperaturas. **Ciência Florestal**, v. 23, n. 1, p. 45-53, 2013.

HARTMANN, H. T. *et al.* **Plant propagation**: principles and practices. 8. ed. New Jersey: Prentice Hall, 2011. 915 p.

KAPPES, C. *et al.* Germinação, vigor de sementes e crescimento de plântulas de milho sob condições de déficit hídrico. **Scientia Agraria**, v. 11, n. 2, p. 125-134, 2010.

LABOURIAU, L. G. **A germinação de sementes**. Washington: OEA, 1983. 174 p.

LOHMANN, L. G. **Bignoniaceae *in* Flora do Brasil 2020 em construção**. Jardim Botânico do Rio de Janeiro, 2010. Disponível em: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB112305. Acesso em: 27 abr. 2020.

LOHMANN, L. G. Check-list das Bignoniaceae do estado de Mato Grosso do Sul. **Iheringia**, **Série Botânica**, v. 73, p. 157-162, 2018. Suplemento.

LORENZI, H. **Árvores brasileiras**: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. 5. ed. Nova Odessa: Plantarum, 2008. v. 1. 368 p.

MAGUIRE, J. D. Speed of germination: aid in selection and evaluation for seedling emergence and vigour. **Crop Science**, v. 2, n. 2, p. 176-177, 1962.

MARQUES, M. A. *et al.* Germination of *Tabebuia chrysotricha* (Mart.) Standl. seeds dried in dry chamber, stored in different environments and submitted to seven levels of osmotic potential. **Científica**, v. 32, n. 2, p. 127-133, 2004.

MARTINS, J. R. *et al.* Seedling survival of *Handroanthus impetiginosus* (Mart ex DC) Mattos in a semi-arid environment through modified germination speed and post-germination desiccation tolerance. **Brazilian Journal of Biology**, v. 75, n. 4, p. 812-820, 2015.

MELLO, C. M. C.; EIRA, M. T. S. Conservação de sementes de ipês (*Tabebuia* spp.). **Revista Árvore**, v. 19, n. 4, p. 427-432, 1995.

PARSONS, R. F. Incidence and ecology of very fast germination. **Seed Science Research**, v. 22, n. 3, p. 161-167, 2012.

RIBEIRO, J. W. F.; PEREIRA, K. C. L.; OLIVEIRA, A. K. M. Germinação de sementes de *Amphilophium crucigerum* (L.) L.G. Lohmann (Bignoniaceae) em diferentes temperaturas. **Natureza online**, v. 16, n. 1, p. 062-068, 2017.

SANTOS, D. L.; SUGAHARA, V. Y.; TAKAKI, M. Efeitos da luz e da temperatura na germinação de sementes de *Tabebuia serratifolia* (Vahl) Nich, *Tabebuia chrysotricha* (Mart. ex DC.) Standl. e *Tabebuia roseo-alba* (Ridl) Sand - Bignoniaceae. **Ciência Florestal**, v. 15, n. 1, p. 87-92, 2005.

SANTOS, P. C. S. *et al.* Water stress and temperature on germination and vigor of *Handroanthus impetiginosus* (Mart. ex DC). **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 22, n. 5, p. 349- 354, 2018.

SILVA, M. L. M *et al*. Germinação de sementes de *Chorisia glaziovii* O. Kuntze submetidas ao estresse hídrico em diferentes temperaturas. **Ciência Florestal**, v. 26, n. 3, p. 999-1007, 2016.

VIEIRA, C. V. *et al*. Stress-associated factors increase after desiccation of germinated seeds of *Tabebuia impetiginosa* Mart. **Plant Growth Regulation**, v. 62, n. 3, p. 257-263, 2010.

VILLELA, F. A.; DONI FILHO, L.; SEQUEIRA, E. L. Tabela de potencial osmótico em função da concentração de polietileno glicol 6000 e da temperatura. **Pesquisa Agropecuária Brasileira**, v. 26, n. 11/12, p. 1957-1968, 1991.