

SEED GERMINATION OF *Pouteria torta* (MART.) RADLK. SUBESP. *torta* IN DIFFERENT ENVIRONMENTAL CONDITIONS

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Resumo

Germinação de sementes de Pouteria torta (Mart.) Radlk. subesp. torta em diferentes condições ambientais. A germinação é considerada uma etapa crítica no processo de produção de mudas para a recuperação ambiental. Desta maneira, entender o comportamento germinativo de espécies nativas com potencial de utilização econômico, contribui com o desenvolvimento dos elos da cadeia de sementes e mudas florestais. Levando-se em consideração as poucas informações sobre a espécie arbórea *Pouteria torta* subesp. *torta*, objetivou-se com este trabalho avaliar a germinação de sementes e formação de plântulas normais, utilizando diferentes substratos e temperaturas. O experimento foi conduzido em laboratório de pesquisa, combinando-se dois substratos (sobre papel e vermiculita) e seis temperaturas (20, 25, 30, 35, 20-30 e 25-35 °C), em câmara de germinação, com delineamento experimental inteiramente casualizado, em esquema fatorial (2x6). A avaliação foi diária, verificando-se a emissão de raiz primária, vigor das sementes e formação de plântulas. Os resultados indicaram que, nas melhores condições, o processo de protrusão da raiz primária ocorreu após 20 dias de teste, com o tempo de germinação prolongando-se por mais de dois meses. Os resultados obtidos indicaram que ocorreu interação de fatores, sendo que a utilização de substrato vermiculita e temperaturas de 35 e 25-35 °C produziu as melhores taxas de germinação e índice de velocidade de germinação, enquanto substrato papel, 30 e 35 °C, melhor tempo médio de germinação. Levando-se em consideração às variáveis: germinação, índice de velocidade de germinação e formação de plântulas normais, as temperaturas de 35 e 25-35 °C, substrato vermiculita, são as mais adequadas para a produção de mudas de *Pouteria torta* subesp. *torta*.

Palavras-chave: Sapotaceae; guapéva; formação de plântulas.

Abstract

Germination is considered a critical step in the seedling production process aiming the recovery of environments. Thus, understanding the germination behavior of native species with potential for economic use contributes to the development of the forest seed and seedling chain. Considering the limited information on the tree species *Pouteria torta* subesp. *torta*, this study aimed to evaluate its seed germination and formation of normal seedlings using different temperatures and substrates. The experiment was conducted in germination chamber in a research laboratory using two substrates (paper and vermiculite) and six temperatures (20, 25, 30, 35, 20-30 and 25-35 °C) in a completely randomized design in a 2x6 factorial arrangement. Daily evaluation was conducted to verify primary root emission, seed vigor, and seedling formation. The results indicated that the primary root protrusion process began after 20 days of testing under the best conditions, with germination time lasting longer than two months. The results obtained also showed that there was interaction between factors, with use of the vermiculite substrate and the temperatures of 35 and 25-35 °C producing the best germination rates and germination speed index, and use of the paper substrate and the temperatures of 30 and 35 °C showing the best mean germination time. Considering the analyzed variables (germination, germination speed index, and formation of normal seedlings), the temperatures of 35 and 25-35 °C and the vermiculite substrate are the most suitable for the production of *Pouteria torta* subesp. *torta* seedlings.

Keywords: Sapotaceae; guapevá; seedling formation.

INTRODUCTION

Sapotaceae, belonging to genus *Pouteria*, is among the families of economic and medicinal importance of the Cerrado biome. It is widespread and used to obtain wood for civil construction and in mixed plantations destined to the restoration of degraded areas, with leaves and fruits for use in folk medicine as antidiarrheal and antimicrobial, as well as for use as food (fruits) (CARVALHO, 2008; ELIAS *et al.*, 2013).

Pouteria torta (Mart.) Radlk. subsp. *torta*, popularly known as ‘guapéva’, ‘abiú’ or ‘pêssego-do-mato’, stands out among the species of this genus. The largest trees can reach 35 m in height and 100 cm in trunk diameter,

occurring from Amapá to Santa Catarina states, in the Atlantic Forest and Cerrado biomes; it is considered a late secondary or climax species, and is cultivated in orchards for the use of its fruits (CARVALHO, 2008).

The Cerrado flora is one of the richest in biodiversity in the world; it has a high degree of endemism and is considered a hotspot for constant threat to its ecosystem, caused by anthropogenic impacts (GRECCHI *et al.*, 2014). Thus, studies and projects have been intensified to recover areas and avoid aggravation of previously detected problems, which resulted in increased seed commercialization and demand for seedlings of native tree species. However, there is still lack of information on the germination behavior of many species, such as *Pouteria torta* (Mart.) Radlk. subsp. *torta*.

However, for the production of seedlings used in areas under recovery processes and of economic use, it is necessary to know the factors that affect the seed germination process of the species, such as light, temperature and water availability (external, environmental factors) or dormancy (internal, intrinsic factor).

The seed germination process includes a sequence of physiological events that are influenced by external (environmental) and internal (dormancy and germination inhibitors and promoters) factors, and each of these factors can act on its own or in interaction with others. This process is considered a biological phenomenon, a result of resumption of embryo growth with subsequent rupture of the integument by the primary root (BEWLEY *et al.*, 2013).

Germination tests may include the use of different environmental factors to evaluate the viability and vigor of a seed lot. The information obtained can be used in forest nurseries to accelerate and homogenize the processes, enabling the production of more seedlings in a shorter time. According to Dousseau *et al.* (2008) and Bewley *et al.* (2013), the most relevant environmental factors for the germination process are water, light, temperature and substrate type. Typically, temperature and substrate variations are the most commonly used to indicate the best conditions for obtaining higher germination rates and normal seedling formation.

Temperature influences the process by affecting the biochemical reactions that determine the entire germination process, changing the final percentage of seed germination and seed vigor (BEWLEY *et al.*, 2013). Some species germinate best at constant temperatures, whereas others alternate high and low germination rates depending on the region of origin of the seeds. According to Brancalion *et al.* (2013), most of the species in the Cerrado biome previously researched germinate better at approximately 25 °C.

The type of substrate and its water retention capacity also influence germination, varying according to its composition. Its function is to provide the seeds with adequate moisture for germination and subsequent seedling formation (DOUSSEAU *et al.*, 2008; BRASIL, 2009). The choice of substrate should consider seed size and moisture requirement, and paper and vermiculite are the most commonly used substrates in laboratory tests (BRASIL, 2009).

Each species has specific requirements, but information on the germination processes of most Brazilian tree species is still scarce, hindering the use of reliable and standardized analysis methods (BRASIL, 2009). For species *Pouteria torta*, Salomão *et al.* (2003) described a germination rate of 25%, not to mention the germination conditions (substrate type and temperature used). This information shows that, despite its importance as a species with great exploitation potential, little is known about the aspects related to the germination and emergence of *Pouteria torta* subsp. *torta* seedlings.

In this context, this study aimed to test the hypothesis that seed germination of *Pouteria torta* subsp. *torta* is favored by the presence of higher temperatures and substrates with greater water retention; to this end, it evaluated different substrates and temperatures on the germination and formation of normal seedlings of this species.

MATERIAL AND METHODS

Botanical material was collected (December 2016) from Legal Preservation areas in the *Parque dos Poderes* region (20°26'16.6" S; 54°32'14.5" W), municipality of Campo Grande, state of Mato Grosso do Sul, Brazil. The collection region belongs to the Cerrado biome, with presence of seasonal forests, regular and dense cerrado areas, and gallery forests, and predominance of planted pastures (*Brachiaria* spp.) for beef cattle raising. Ten matrices of species *Pouteria torta* subsp. *torta* were used, considering size (height >5 m) and minimum distance between trees (>1 km).

A voucher specimen was mounted and used in the process of species confirmation, by analytical key and specialized bibliography, and deposited as a taxonomic document at the Anhanguera-Uniderp University herbarium (no. 8512). The collected material was sent to the Research Laboratory on Environmental Systems and Biodiversity and seed water content was determined by the oven method at 105 ±3 °C for 24 h (BRASIL, 2009) using four repetitions of 10 seeds. On average, the lots weighed 60.81 g before the drying process, that is, 6.081 ±0.001 g seed⁻¹. According to Carvalho (2008), these seeds can be considered large and there is thus need for adaptation to the Seed Analysis Rules (SAR).

After manual removal of the fruit pulp, the seeds were immersed in 1% sodium hypochlorite for 3 min and then washed in running water for 1 min. Using previously sterilized materials, the disinfected seeds were distributed in transparent plastic boxes (11x11x3.5 cm) on two substrates, paper (two sheets of Germitest® paper) and vermiculite, and kept in germination chamber under six temperatures (20, 25, 30, 35, 20-30 and 25-35 °C) and two light conditions: 12 h constant white-light (± 660 lux) and 12 h constant darkness. When necessary, the substrates were moistened with distilled water. Due to the occurrence of fungi in certain treatments, the seeds were washed with sodium hypochlorite and the substrates were replaced and moistened with an aqueous solution containing 0.2% iprodione fungicide.

Evaluation was performed daily considering the germination of seeds with primary root emission >2 mm (OLIVEIRA *et al.*, 2014), and the non-germinated seeds were evaluated by the tetrazolium test (BRASIL, 2009) with modifications. Germination percentage and seed vigor were quantified (mean germination time in days - MGT and germination speed index - GSI), as well as the relative frequency of germination (used for the substrate with the best results, vermiculite). The initial seedling growth was determined by measuring the size of the primary root (seedling collar to the apical meristem of the root system, in mm) and shoot part (seedling collar to the apical meristem, in mm) were analyzed using a digital caliper.

The experimental design was completely randomized, with four replications of 25 seeds per treatment, in a 2x6 factorial arrangement (substrate x temperature). The values were initially tested for the assumptions of normality of residues and homogeneity between variances. When these assumptions were not met, the data were transformed and analysis of variance (ANOVA) was applied using the Tukey's test (5%). The data were processed using the *Assistat* software. For a better understanding of the results, the means presented in the tables correspond to unprocessed data.

RESULTS

The seeds of *Pouteria torta* subsp. *torta* had 36.2% water content.

The species presents hypogeal germination, with reserve cotyledons (phanerocotyledonar) and axis (unipolar).

The results indicated that there was interaction between factors, with use of the vermiculite substrate and the temperatures of 35 and 25-35 °C providing the best germination rates and germination speed index, and use of the paper substrate and the temperatures of 30 and 35 °C showing the best mean germination time. Considering the analyzed variables (germination, germination speed index, and formation of normal seedlings), the temperature of 35 °C and the vermiculite substrate are the most suitable for the production of *Pouteria torta* subsp. *torta* seedlings.

Table 1. Analysis of variance, germination (G%), germination speed index (GSI) and mean germination time in days (MGT) of the *Pouteria torta* subsp. *torta* seeds submitted to the temperatures of 20, 25, 30, 35, 20-30 and 25-35 °C on two substrates (paper and vermiculite)

Tabela 1. Análise de variância, germinação (G%), índice de velocidade de germinação (IVG) e tempo médio de germinação em dias (TMG) de sementes de *Pouteria torta* subesp. *torta*, submetidas às temperaturas de 20, 25, 30, 35, 20-30 e 25-35 °C, sobre dois substratos (papel e vermiculita)

G%						
Source of variation	G. L.	Sum of squares	Medium square	F		
Substrate (F1)	1	500.52083	500.52083	465.0000 **		
Temperature (F2)	5	389.60417	77.92083	72.3910 **		
Interaction F1xF2	5	132.60417	26.52083	24.6387 **		
Treatments	11	1022.72917	92.97538	86.3771 **		
Residuals	36	38.75000	1.07639			
Total	47	1061.47917				
Germination (%)	20 °C	25 °C	30 °C	35 °C	20-30 °C	25-35 °C
On vermiculite	24 aB	28 aB	24 aB	60 aA	32 aB	64 aA
On paper	4 bCD	16 bB	8 bC	4 bD	8 bC	32 bA
LSD	Column			Line		
	1.49 ($p < 0.01$)			2.61 ($p < 0.01$)		

GSI						
Source of variation	G. L.	Sum of squares	Medium square	F		
Substrate (F1)	1	3.89880	3.89880	1233.3638 **		
Temperature (F2)	5	5.19367	1.03873	328.5975 **		
Interaction F1xF2	5	2.48690	0.49738	157.3434 **		
Treatments	11	11.57937	1.05267	333.0062 **		
Residuals	36	0.11380	0.00316			
Total	47	11.69317				
GSI	20 °C	25 °C	30 °C	35 °C	20-30 °C	25-35 °C
On vermiculite	0.50 aC	0.60 aBC	0.65 aBC	1.86 aA	0.72 aB	1.4 aA
On paper	0.09 bD	0.31 bB	0.33 bB	0.14 bCD	0.22 bBC	1.06 bA
LSD	Column			Line		
	0.081 ($p<0.01$)			0.120 ($p<0.01$)		

MGT						
Source of variation	G. L.	Sum of squares	Medium square	F		
Substrate (F1)	1	1132.96333	1132.96333	441.1040 **		
Temperature (F2)	5	2033.14417	406.62883	158.3154 **		
Interaction F1xF2	5	1095.08667	219.01733	85.2714 **		
Treatments	11	4261.19417	387.38129			
Residuals	36	92.46500	2.56847			
Total	47	4353.65917				
MGT	20 °C	25 °C	30 °C	35 °C	20-30 °C	25-35 °C
On vermiculite	50.7 aB	48.3 aB	43.8 bB	36.7 bA	47 bB	48.9 bB
On paper	47 aD	54.8 bD	24.5 aA	28 aAB	36 aC	31.9 aBC
LSD	Column			Line		
	2.30 ($p<0.01$)			3.41 ($p<0.01$)		

**Significant at 1% probability level ($p<0.01$); LSD = value of the least significant difference for the chosen test; LSD = TSD (Tukey Significant Difference); Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically by Tukey's test ($p>0.05$).

Approximately 60% of the seeds maintained at the temperatures of 20 and 20-30 °C on paper substrate were considered viable and approximately 40% of those kept at the temperatures of 20, 25 and 30 °C on vermiculite substrate were viable. These were the groups with the largest number of viable and non-germinated seeds (Table 2).

In contrast, the temperatures of 25, 30, 35 and 25-35 °C on paper substrate showed a number of non-viable (dead) seeds $\geq 60\%$, and the temperatures of 20, 25, 30 and 20-30 °C on vermiculite substrate presented between 32 and 40% of non-viable seeds (Table 2).

Table 2. Viable, non-viable and germinated seeds (%) of the *Pouteria torta* subsp. *torta* submitted to the temperatures of 20, 25, 30, 35, 20-30 and 25-35 °C on two substrates (paper and vermiculite)

Tabela 2. Sementes viáveis, inviáveis e germinadas (%) de *Pouteria torta* subesp. *torta*, submetidas às temperaturas de 20, 25, 30, 35, 20-30 e 25-35 °C, sobre dois substratos (papel e vermiculita)

T °C	On paper				On vermiculite			
	Viable (%)	Non-viable (%)	Total (%)	Germinated (%)	Viable (%)	Non-viable (%)	Total (%)	Germinated (%)
20	60	36	96	4	40	36	76	24
25	16	68	84	16	40	32	72	28
30	16	76	92	8	40	36	76	24
35	-	96	96	4	12	28	40	60
20-30	60	32	92	8	28	40	68	32
25-35	8	60	68	32	20	16	36	64

The primary root protrusion process began after 20 days of testing at the temperatures 25-35 °C (paper) and 35 °C (vermiculite), followed by on the 24th day at 30 °C (paper and vermiculite), on the 28th day at 35 °C (paper), and on the 29th day at 25-35 °C (vermiculite).

Lower temperatures enabled longer protrusion time, with the temperature of 20 °C promoting primary root protrusion on the 36th (vermiculite) and 47th (paper) days, 25 °C on the 36th day (paper and vermiculite), and 20-30 °C on the 36th day (paper and vermiculite).

Regarding the relative frequency, germination was not synchronized, presenting a distribution over the incubation time and heterogeneous for all treatments (Figure 1).

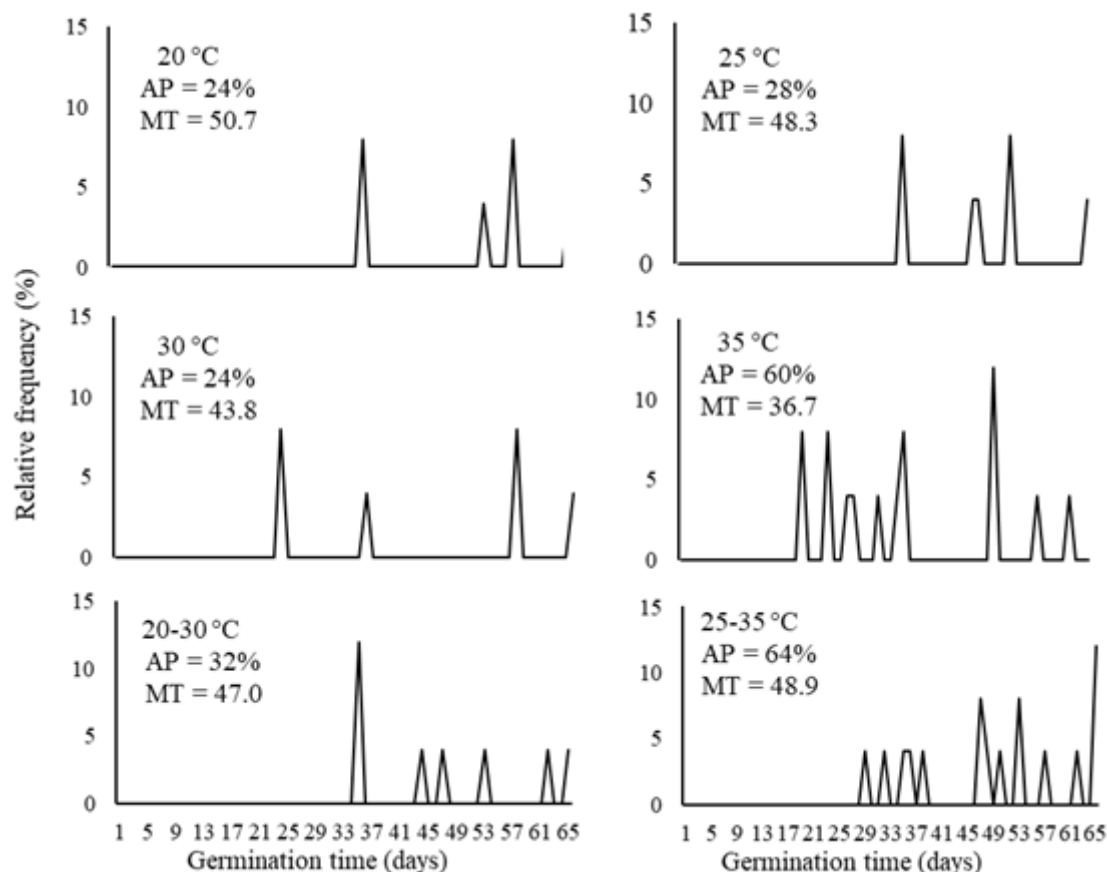


Figure 1. Relative frequency of germination of *Pouteria torta* subsp. *torta* seeds submitted to treatment on vermiculite and different temperatures in germination chamber. AP = Average percentage of germinated seeds; MGT = mean germination time (days).

Figura 1. Frequência relativa de germinação de sementes de *Pouteria torta* subsp. *torta* submetidas ao tratamento sobre vermiculita e diferentes temperaturas em câmara de germinação. PG = porcentagem média de sementes germinadas e TM = tempo médio (dias) de germinação.

Seedling Formation

On the paper substrate, germinated seeds (primary root protrusion) at all temperatures tested did not form normal seedlings. On the vermiculite substrate, the temperatures of 20 and 25 °C also did not provide the formation of normal seedlings (Table 3).

The temperatures of 30, 35, 20-30 and 25-35 °C (vermiculite) allowed the formation of complete seedlings, with the best percentages occurring at 35 and 25-35 °C, which also generated the largest seedlings (Table 3).

Table 3. Germination (%), normal seedlings (NS) (%), and root and shoot growth (mm) of seeds of *Pouteria torta* subsp. *torta* kept on two substrates, paper (P) and vermiculite (V), at the temperatures of 20, 25, 30, 35, 20-30 and 25-35 °C

Tabela 3. Sementes germinadas (%), plântulas normais (%) e crescimento da raiz e parte aérea (mm) de sementes de *Pouteria torta* subesp. *torta* mantidas sobre dois substratos, papel e vermiculita, temperaturas de 20, 25, 30, 35, 20-30 e 25-35 °C

T °C	Germination P (%)	NS (%)	Root (mm)	Shoot (mm)	Germination V (%)	NS (%)	Root (mm)	Shoot (mm)
20	4	0	-	-	24	0	-	-
25	16	0	-	-	28	0	-	-
30	8	0	-	-	24	8 b	13.8 a	1.5 b
35	4	0	-	-	60	32 a	11.8 a	3.2 a
20-30	8	0	-	-	32	16	5.5 b	0.9 b
25-35	32	0	-	-	64	28 a	10.5 a	2.0 ab

*Means followed by the same lower case letter in the column do not differ statistically by the Tukey's test ($p>0.05$).

DISCUSSION

Water content

The water content found (36.2%) is generally associated with species considered sensitive to desiccation, in which moisture loss would lead to decreased viability, with seed deterioration occurring in a short time (BEWLEY *et al.*, 2013). Recent research indicates that differences in desiccation tolerance may depend on the degree of maturation before dispersion (BARBEDO *et al.*, 2013; BEWLEY *et al.*, 2013). According to Carvalho (2008), the longevity of *Pouteria torta* seeds is very short, with rapid loss of vigor after harvest and seeds presenting recalcitrant characteristics, with water loss leading to physiological damage.

Salomão *et al.* (2003) reported a value 43% of water content for *P. torta*, similar to that found in this study, but did not identified the subspecies evaluated. Other species of the same genus showed higher values, such as 46% for *P. ramiflora* (SALOMÃO *et al.*, 2003) and 47.2% for *P. campechiana* (Kunth) Baehni (COSTA *et al.*, 2010). The values mentioned indicate that seeds of genus *Pouteria* may have high water content, perhaps a characteristic of this genus, which would provide germination in a short time and rapid loss of viability. Salomão *et al.* (2003) and Carvalho (2008) recommended that the seeds of *Pouteria torta* be placed to germinate when freshly harvested to obtain good germination because their viability is short.

According to Salomão *et al.* (2003), other seeds of Cerrado species also present similar behavior, with high water content, such as *Campomanesia adamantium* (Cambess.) O. Berg., *Eugenia dysenterica* DC (Myrtaceae) and *Hancornia speciosa* Gomez (Apocynaceae). According to Barbedo *et al.* (2013) and Bewley *et al.* (2013), species with high water content usually originate from habitats that allow rapid seed establishment after dispersal of the mother plant, which represents an evolutionary adaptation of these species. However, this situation was not observed for *Pouteria torta* subsp. *torta*, because the species distributes its germination period over several weeks (high MGT).

Germination

According to Carvalho (2008), species germination is hypogeal or cryptocotyledon, which was observed in this study. The morphofunctional types of germination and seedlings described for other species of this genus, such as *P. fimbriata* Baehni, *P. multiflora* (A.DC.) Eyma and *P. macrophylla* (Lam.) Eyma present hypogeal germination (VILLACHICA *et al.*, 1996). Camargo *et al.* (2008) also reported the same for *P. guianensis* Aubl. and some other species of this family. In contrast, *P. jariensis* Pires & T. D. Penn. presented phanerocotyledon seedlings, but with epigeal germination. The germination pattern of a species is determined by the environment and its establishment strategies, which may vary depending on the place of origin. Thus, result discrepancies may occur in studies on seeds of the same species from different lots.

Root protrusion onset and relative frequency

Primary root protrusion began at higher temperatures (30, 35 and 25-35 °C), whereas lower temperatures (20, 25 and 20-30 °C) provided longer protrusion time. The results, under the best conditions, are similar to those

described by Carvalho (2008), with emergence occurring between 25 and 50 days after seeding. Villachica *et al.* (1996) observed, for *P. macrophylla*, beginning of germination 24 days after the beginning of the experiment, indicating slow and uneven germination of the evaluated species. These reports suggest the presence of seed coat dormancy, and this characteristic, associated with inadequate substrate, may be responsible for failure in the emergence process. Low germination speed and seedling emergence uncertainty may be characteristic of the species under natural conditions.

The relative germination frequency was not synchronized, with distribution over the incubation time and heterogeneous for all temperatures. As seed germination is not fully synchronized, it was possible to verify a series of temporal variations in this species (Figure 1), starting from the 20th day and extending to the 65th day, demonstrating their distribution over time. The frequency distribution for *P. torta* subsp. *Torta*, the delay in germination, and its temporal distribution suggest seed adaptation to increase the probability of survival in highly heterogeneous habitats such as the Cerrado.

Oliveira and Nunes (2013), evaluating the seed germination of *Rheedia brasiliensis* (Mart.) Planch. & Triana collected in flooded areas and Oliveira *et al.* (2014), assessing the seed germination of *Miconia albicans* (Sw.) Triana obtained in Cerrado areas, also demonstrated long temporal distribution in germination, and correlated this event with the place of collection, which presented variations in their environmental conditions. This behavior may be important for germination distribution (BRANCALION; MARCOS FILHO, 2008), a strategy that provides greater efficiency in seedling establishment, as it can meet ideal conditions at some point.

Germination percentages

Brancalion *et al.* (2010), performing a review of existing information at the best temperatures for seed germination of Cerrado biome species, reported that most of the species surveyed germinate better between 25 and 30 °C, with higher concentration around 25 °C. *Pouteria torta* subsp. *torta* presented a different germination behavior. The results indicated that, considering that the most important is the germination of a larger number of seeds in a shorter time (high vigor), the best treatment for the species in question is the vermiculite substrate at the temperatures of 35 and 25-35 °C, with 60 and 64% germination, respectively.

Significant results with the use of vermiculite were also reported by Bassaco *et al.* (2014) with seeds of *Sebastiania brasiliensis* Spreng. and by Pereira *et al.* (2015) with *Moringa oleifera* Lam., in which this substrate provided better germination and growth, demonstrating its suitability to germination tests. The large water retention capacity and greater contact area of the vermiculite substrate were probably the factors that contributed to a higher germination percentage of *Pouteria torta* subsp. *torta* seeds compared with the paper substrate.

Although a good germination rate has occurred at certain temperatures (35 e 25-35 °C), vermiculite substrate, at the end of the experiment viable seeds still existed (Table 2), demonstrating that the germination process could continue to occur, increasing the final germination percentage. These results may indicate some kind of numbness, integumentary or embryonic.

In the best conditions, germination >25% was obtained, reaching 60% (vermiculite, 35 °C) or 64% (vermiculite, 25-35 °C), with 12 and 20% of viable and non-germinated seeds, respectively.

According to Monteiro *et al.* (2007), seeds of *Pouteria torta* have sturdy coat. Salomão *et al.* (2003) describe values between 20 and 23% dormancy and 25% germination. The possible dormancy reported may be exogenous due to the impermeability of the integument to water or gases, and may be interrupted by processes that cause rupture of the integument, allowing water absorption and germination, as at high temperatures.

Results indicate that high temperatures would be more propitious to obtain higher germination rates, enabling the seed rehydration process or acting as a sign of environmental conditions (BEWLEY *et al.*, 2013). Pereira *et al.* (2013), evaluating seeds of *Peltophorum dubium* (Spreng.) Taub., confirmed that relatively high temperatures (35 °C) are essential to overcome the dormancy of the species. Zucareli *et al.* (2015), assessing the germination of *Passiflora incarnata* L., also demonstrated that the temperature of 35 °C was the most appropriate for seed germination, corroborating the results found in the present study.

The alternating temperature of 25-35 °C was also effective to accelerate species germination. According to Brancalion *et al.* (2008), alternating temperature regimes may be associated with overcoming the impermeability of the integument to water, allowing seed hydration and germination. Masin *et al.* (2017) confirmed that the use of alternating temperatures is adequate to obtain good germination rates.

According to Liu *et al.* (2013) and De Vitis *et al.* (2014), these temperatures indicate that the species is adapted to succession environments, such as in clearings, where pioneer species occur at the early stages and seeds

may require alternating temperatures to optimize germination. In contrast, Yu *et al.* (2008) reported that, for some species in clearing environments, light variations interfered with germination behavior, whereas for others, light differences did not affect germination. This need probably reflects an adaptation to natural habitat fluctuation or may be associated with the dormancy process. Whatever the cause, this requirement can, in most cases, provide species with an adaptive advantage.

Regarding the lower vigor found at lower temperatures, the results could be expected because, according to Bewley *et al.* (2013), a decrease in temperature slows down metabolic activities, causing reduction in germination percentage and delay in the germination process. However, the temperature of 30 °C, for example, would not be considered low (Table 2). As previously stated, higher temperatures may provide higher gas and water diffusion rates, inducing better germination.

The lower germination performance on paper treatments, $\leq 16\%$ germination, except for 25-35 °C, which reached 32% (also a small rate), may be related to its characteristics, which allow less seed contact with the substrate, leaving it more exposed to water restriction, mainly due to its size, considered large by Carvalho (2008). According to Brazil (2009) and Bewley *et al.* (2013), water availability in the substrate and its variation, a common factor in this type of work, often causes reduction in germination values because water reactivates metabolism and is directly and indirectly involved in all stages of the germination process. Of the substrates used, paper had the lowest water retention and seed contact capacity, resulting in smaller germination and vigor mean values.

Seedling formation

As for analysis of the seedlings, the use of vermiculite allowed the formation of complete seedlings at the temperatures of 30, 35, 20-30 and 25-35 °C, with emphasis on 35 and 25-35 °C, which also showed the highest average growth. The results showed that higher temperatures are needed for germination and formation of normal seedlings in a shorter time, a situation confirmed by the evaluation of non-germinated seeds, with a larger number occurring at 20 °C. Exposure of seeds to low temperatures, such as 20 °C, even for a 12 h photoperiod, led to lower germination and growth rates, indicating sensitivity of the seeds to this situation.

According to the study conducted by Oliveira and Jardim (2013) with *P. ramiflora* seeds, emergence occurred as of the 28th day after sowing, extending to the 114th day, and reaching 75% germination, results similar to the findings of this study. The data showed that the process of germination and seedling formation is long and may be a characteristic of the genus *Pouteria*.

Regarding the substrates, paper was not suitable, not allowing the formation of normal seedlings at any temperature tested, whereas vermiculite provided formation of normal seedlings probably because of its good structure and high water retention capacity, being the most suitable substrate for this species.

CONCLUSION

Considering the analyzed variables (germination, germination speed index, and formation of normal seedlings), the temperatures of 35 and 25-35 °C and the vermiculite substrate are the most suitable for the production of *Pouteria torta* subsp. *torta* seedlings.

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