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Seed vigor and germination of facheiro plants (*Pilosocereus catingicola* (Gurke) Byles & Rowley Subsp. *salvadorensis* (Werderm.) Zappi (Cactaceae) at different temperatures

Vigor e germinação de sementes de facheiro (*Pilosocereus catingicola* (Gürke) Byles & Rowley subsp. *salvadorensis* (Werderm.) Zappi (Cactaceae) em diferentes temperaturas

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Abstract

Several species of endemic Cactaceae are found in northeastern Brazil, which are important plants to the local fauna and flora; nevertheless, there are only a few studies assessing the germination of this plant genus. Understanding the germination of species native to the Caatinga is essential to subsidize conservation actions for such ecosystem. The objective of this study was to investigate the influence of three localities and different temperatures on the vigor and germination of facheiro seeds. The experiment was conducted by evaluating seed vigor and germination in three distinct areas (Arara, Bananeiras, and Boa Vista) at different temperatures (20, 25, 30, 35, 40, and 20-30 ºC). Quantitative data were submitted to polynomial regression analysis at 5% significance with four replicates of 50 seeds. In Arara, germination rates at 20 and 25 ºC reached 96% and, at 30 ºC, 86%. The temperatures of 25 and 30 ºC presented the best germination speed index. For the three studied areas, the highest germination rates were recorded at a constant temperature of 25 ºC and at the alternating temperature (20-30 ºC). Yet the highest germination speed was reached at 30 ºC. Based on its sexual propagation, the taxon in question is able to survive in environments with temperatures ranging from 20 to 30 ºC, as seen in the studied habitats.

Key words: Agreste of Paraíba state. Facheiro. Physiological potential.

Resumo

No Nordeste brasileiro ocorrem diversas cactáceas endêmicas de grande importância para a fauna e flora, entretanto poucos são os estudos envolvendo germinação em cactáceas no Brasil, principalmente, no Nordeste. É de fundamental importância o conhecimento da germinação das espécies nativas da

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Caatinga, para subsidiar ações conservacionistas desses ecossistemas. O objetivo deste trabalho foi investigar a influência de diferentes localidades e temperaturas no vigor e germinação de sementes de facheiro. O experimento foi realizado, avaliando o vigor e a germinação de sementes das três áreas selecionadas (Arara, Bananeiras e Boa Vista) em diferentes temperaturas (20ºC, 25ºC, 30ºC,35ºC, 40ºC e 20-30ºC). Os dados quantitativos foram submetidos à análise de regressão polinomial à 5% de significância, com quatro repetições de 50 sementes. Para a localidade de Arara-PB, a germinação nas temperaturas de 20 e 25 ºC foi de 96%, e na temperatura de 30 ºC, a germinação foi de 86%. As temperaturas de 25ºC e 30ºC apresentaram os melhores Índice de Velocidade de Germinação. A espécie apresentou nas três áreas de ocorrência, germinação elevada nas temperaturas constantes de 25 e alternada 20-30ºC. Os maiores índices de velocidade de germinação foram obtidos na temperatura de 30 ºC. O táxon nos habitats estudados têm capacidade de sobrevivência em ambientes que apresentem variações de temperatura de 20 a 30ºC quanto à sua propagação sexuada.
Palavras-chave: Agreste paraibano. Facheiro. Potencial fisiológico.

Introduction

Cacti are among the most iconic groups of plants because they are adapted to drought conditions, and they are evolved and diversified under ecosystems of xeric conditions (MENEZES et al., 2016)**.** The semiarid Caatinga and the seasonal Cerrado are among most important areas with cacti diversity in east Brazil, bringing together a significant amount of endangered species of the Cactaceae family (GOETTSCH et al., 2015).

The region contains several endemic Cactaceae species important to the regional fauna and flora. Among them are the mandacaru (*Cereus jamacaru* P. DC.), facheiro (*Pilosocereus pachycladus* Ritter), xiquexique [*Pilosocereus gounellei* (A. Weber ex K. Schum.) Bly ex Rowl], and coroa-de-frade (*Melocactus bahiensis* Britton & Rose), which are mainly used for animal feed during the dry season in the region (BRITO CAVALCANTI et al., 2007). *Pilosocereus* Byles & Rowley is one of the most representative genera of the Cactaceae family from the Brazilian flora, containing 29 species—26 are endemic—of the semiarid region (HUNT et al., 2006; ZAPPI et al., 2015).

The Caatinga has undergone several threats over the years, decreasing the natural populations and putting some Cactaceae species at risk of extinction (SILVA et al., 2011). The author also reports that the main threats for cacti are related to habitat fragmentation, mainly because of deforestation, agricultural development, and many other types of environmental disturbances, such as the human transit, urban sprawl, animal trampling, and Poaceae invasion of areas. In addition to these factors, large quantities of seeds and plants are illegally collected to supply the horticulture and ornamental markets, and rocky outcrops are destroyed through mining.

Germination performance of the native species from Caatinga is fundamental to subsidize actions to conserve these ecosystems. Therefore, determining suitable technologies to enable the use of seeds from native cactus species that develop in these regions constitute important tools for the implementation of afforestation and reforestation programs in Northeastern Brazil. Germination and viability studies of native Cactaceae seeds are scarce in the Northeast, and few results can be found in the scientific literature (ABUD et al., 2012).

Cactaceae species are propagated by two methods: sexual or asexual. The sexual propagation is not widely used due to the lack of information about this method. In sexual propagation, seedlings grow slowly, but they can be produced in great quantity. The seeds provide genetic variations and several desirable morphological characteristics (ABUD et al., 2010).

In many cases, the germination test is insufficient to evaluate the physiological quality of seeds; using other evaluation methods are necessary, such as vigor tests (VALADARES; PAULA, 2008), average germination time, and germination speed.

The rules for seed testing provide no information about the species; however, knowledge about the optimal conditions for germination is fundamental, especially temperature, because these factors vary according to the seeds and species (GUEDES et al., 2009).

Temperature affects the germination rate; the optimum temperature provides a maximum percentage of germination in a shorter period, while maximum or minimum temperatures result in small germination rates or even death of the embryo (CARVALHO; NAKAGAWA, 2012).

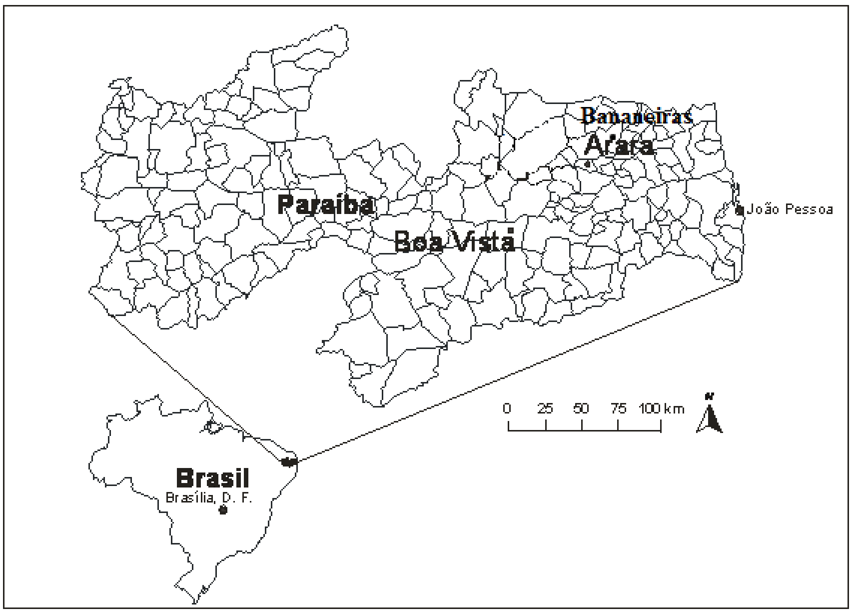
The genus Pilosocereus, as well as other species of this family, contributes to the sustainability of the Caatinga biome (CORREIA et al., 2011). The facheiro and other species of the genus, such as *Pilosocereus gounellei* (F.A.C. Weber) Byles & Rowley subsp. *gounellei* (xiquexique), present economic importance to the region.

Therefore, knowing the eco-physiological aspects of the germination of facheiro seeds from different locations help in understanding the establishment of the seeds at different temperatures. The objective of this study was to evaluate the germination and vigor of *Pilosocereus catingicola* (Gürke) Byles & Rowley Subsp. *Salvadorensis* (Werderm.) Zappi (Cactaceae) at different temperatures.

Material and Methods

Seeds used in the experiment were extracted from fresh ripe fruits in December 2014. They were harvested from natural populations of cacti from the municipalities of Arara (25 M 192007 9243179 UTM), Bananeiras (25 M 203813.08 9259923.81 UTM), and Boa Vista (24 M 698981 9133272 UTM), all located in the State of Paraíba, Brazil. The forest fragments of the Caatinga sampled are located in the Agreste mesoregion of the Paraíba state (Figure 1).

Figure 1. Geographical scope of *P. catingicola* subsp. *salvadorensis*, and location of the studied municipalities in the Agreste region of the Paraíba state, Brazil.



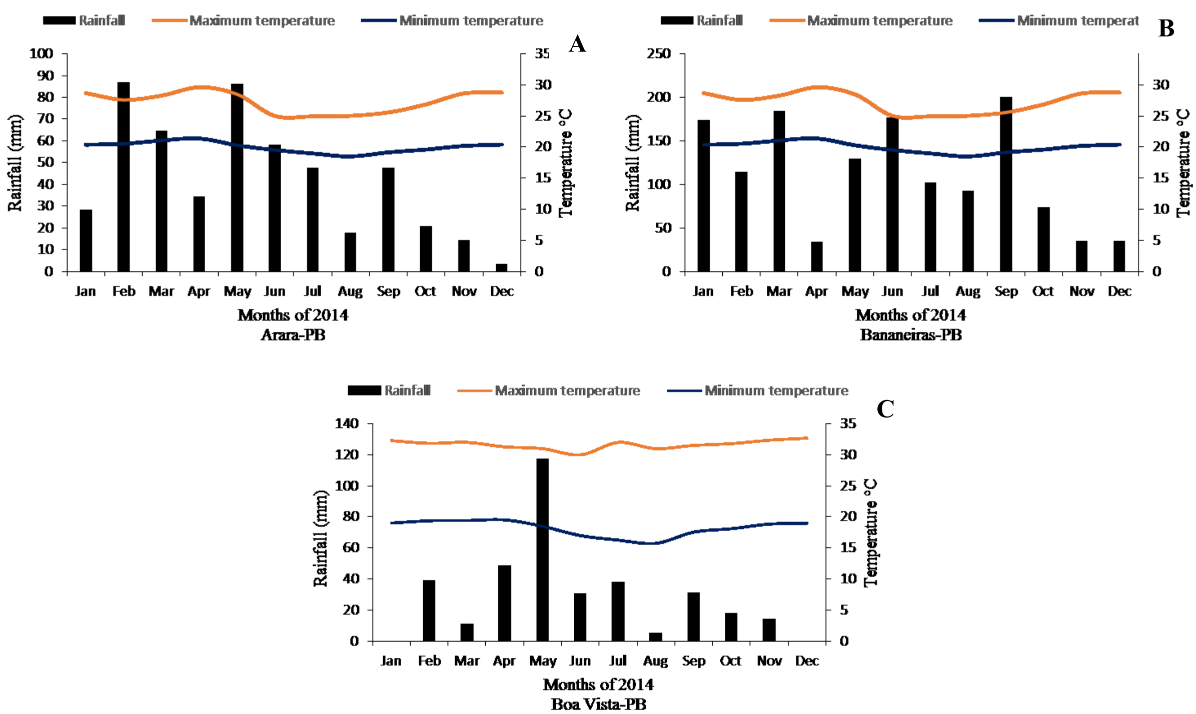
The three areas were chosen based on the high density of *P. catingicola* subsp. *salvadorensis* along the landscape; each one is distinct in terms of use and conservation. The three study areas are private properties.

The area in Arara is located in the Agreste mesoregion of the Paraíba state in the Borborema Plateau formed by massifs and high hillock, with the presence of Neosols, with variable fertility between medium and high (CPRM, 2005a). The climate is tropical and rainy with a dry summer and an average rainfall of 666.13 mm year^{-1}. The Caatinga is in the process of secondary succession, with constant woodcutting; the cattle and goats grazing during the dry season also affect the area (BARBOSA, 2015).

The municipality of Bananeiras is located in the Agreste mesoregion of the Paraíba state at an altitude ranging from 650 to 1,000 meters. Local soils are Neosols with an average natural fertility and deep Podzolics with clayey texture and mean to high natural fertility. The area has a rainy tropical climate with dry summers, and the rainy season from January/ February to September/October (CPRM, 2005b). The Caatinga is in the process of intermediate succession; in this biome, cattle, equines, and goats are used graze during the dry season, what affects the area.

The area in Boa Vista has an average to high fertility and a rainy tropical climate and hot dry summer. Boa Vista is covered by Caatinga plant formations where the plant species pass through deciduous in the dry season. The average annual rainfall is 443.93 mm year^{-1}, characterizing as the most xeric Caatinga among the areas of *P. catingicola* subsp. *salvadorensis*. The soil surface is smoothly undulated with medium-deep Planosols formations with average fertility. In addition, the soil surface is well drained with moderate acidity. Deep clayish Podzolics with average natural fertility are also found. Poorly drained Planosols and rock outcrops along the landscape compound this area (CPRM, 2005c). The Caatinga in Boa Vista is considered one of the most conserved areas, but more recently, the entry of goatherds was verified for controlled grazing during the dry season (BARBOSA, 2015).

Figure 2. Average, maximum, and minimum monthly rainfall and temperature of the municipalities of Arara (a), Bananeiras (b), and Boa Vista (c).



Rainfall data were acquired from the Executive Agency for Water Management in the state of Paraíba during the year of 2014 (AESA, 2017), and the maximum and minimum average temperatures (Figure 2) were acquired by consulting the Meteorological Database from the Nacional Institute of Meteorology (INMET, 2017).

Biometry of the fruit

After harvesting the fruits in the three sample areas, they were packed in paper bags and transported to the Laboratory of Seed Technology of the Centre for Human, Social, and Agrarian Sciences of the Federal University of Paraíba. Biometric measurements for length, diameter, and fruit weight were performed with the aid of a digital caliper with a resolution of 0.01 mm and an analytical scale with 0.01 decimal places. The length of the fruit was measured from the base and the apex of the fruit and the diameter was measured in the middle of the fruit. The fruits were pulped in a sieve and washed under running water to extract the seeds. Then, the seeds were dried in the shade for two days under lab conditions at 25 *ºC*.

Germination: The test was conducted in germination boxes (Gerbox), using a germination paper test (Germitest) as the substrate, with two paper sheets on the bottom of the Gerbox. The seeds were placed on top of the paper and covered with another leaf. There were four replications of 50 seeds total. The substrate was moistened with distilled water 2.5 times the mass of the non-hydrated paper (BRASIL, 2009). The seeds were placed in germinators regulated at constant temperatures of 20, 25, 30, 35, 40 ºC, and one germinator at an alternating set of 20-30 ºC, with 12 hours of photoperiod for each temperature. Seeds with the radicle emerging were considered germinated. The seedlings were counted until the 30th day after sowing when they stabilized.

Vigor: This variable was indirectly quantified by the average time of germination in days, quantifying the germination from the kinetic viewpoint, t = Σni.ti/Sni (LABOURIAU; AGUDO, 1987) and by the germination speed index (GSI = G1/N1+ G2/N2 + ... Gn/Nn) (MAGUIRE, 1962). According to the tests of normality and homogeneity of variances, we did not need to transform the data of GSI (OLIVEIRA et al., 2015).

Statistical analysis of the data was performed using a completely randomized experimental design with four replicates of 50 seeds and treatments distributed in a factorial scheme 3×6 (3 localities and 6 temperatures). The data were submitted to ANOVA. Polynomial regression was performed for the constant temperatures in the studied locations.

Results and Discussion

Table 1 shows the biometric data of the fruit. The fruit from the municipality of Bananeiras presented larger weight, length, and width, which can be connected to the high precipitation of Bananeiras, (Figure 2). Abud et al. (2010), studying fruit of *Pilosocereus pachycladus* F. Ritter, observed fruit with the width of 50.53 ± 5.01 and a length of 38.13 ± 4.52. The fruit widths from Arara, Bananeiras, and Boa Vista were smaller than those studied by Abud et al. (2010), featuring larger standard deviations. The fruit from Boa Vista presented the lowest standard deviations for all variables. The fruit from the Arara locality showed an average weight of 34.33 ± 16.28, Boa Vista 35.03 ± 5.77, and Bananeiras 55.28 ± 13.99.

The differences found among the facheiro fruit may be related to the variation of each environment, the use of nutrients, water resources available. In addition, the genotypic diversity of the populations can also result in different phenotypic characteristics for the species (ISMAEL, 2009; SILVA et al., 2012). Figure 2 shows a direct relationship between the rainfall rate and the size of the fruit in the municipality of Bananeiras. The city receiving more rainfall presented larger fruit than the other localities. When studying the phenology of chiropterophilous and sphingophilous species in the

Caatinga, Lucena (2007) showed that the specimens of the genus *Pilosocereus* occurred regularly during the study period, presenting reproductive structures, such as flowers and fruits, throughout the year with a higher intensity at the beginning of the rainy season. Another observationwas the manifestation of this interspecific synchronous phenophases during the peaks (BARBOSA, 2015).

Table 1. Facheiro fruit biometric collected in areas of Caatinga in the municipalities of Arara, Bananeiras, and Boa Vista, Westland of Paraíba State in Northeastern Brazil.

Characteristics	Arara	Bananeiras	Boa Vista
Width (mm)	44.37 ± 11.38	47.84 ± 7.10	43.43 ± 4.74
Length (mm)	34.30 ± 6.69	42.41 ± 5.08	33.66 ± 2.75
Weight (g)	34.33 ± 16.28	55.28 ± 13.99	35.03 ± 5.77

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Table 2 shows the analysis of the variance of the germination and speed of germination seed index for different locations tested at different temperatures. The location and temperature, isolated factors, and the interaction of these factors was significant to this study.

Regarding the effect of temperature on seed germination, one can note that rates were higher in the temperatures of 20-30, 25, and 30 ºC, regardless of the locality. In the studied areas, the facheiro seeds support a temperature variation because the temperature of 20-30 ºC was favorable for the germination of seeds, showing a germination of 80%. The temperatures of 20 (except in Arara), 35, and 40 ºC were detrimental to the germination process of facheiro, but the alternating temperature was favorable in the three localities, which may infer that the seeds of this species are adapted to seek sharp changes in temperatures in their habitat. Rojas-Aréchiga and Vásquez-Yanes (2000) ensure that the optimal temperature for germination of cactaceous seeds is around 25 ºC, as verified in this study. Guedes et al. (2009) found the temperature of 30 ºC was more suitable for conducting tests of germination and vigor in *Cereus jamacaru* DC seeds.

Table 3 compares the temperatures within each locality; seeds coming from Arara have the highest germination rates at temperatures of 20 and 25 ºC. These treatments are similar statistically, followed by the temperature at 30 ºC. The highest germination values were obtained at 25 ° C for seeds from Boa Vista, followed by temperatures of 20-30 and 30 ºC. The temperatures of 20, 35, and 40 ºC, (except in Arara) were harmful to the germination process of facheiro seeds. However, the alternating temperature of 20-30 ºC was favorable to the three localities; this shows that the seeds of this species are adapted to sudden temperature variations in their habitat. When evaluating the effect of the localities at each temperature, the seeds from Arara presented high germination at 20 ºC, which differs statistically from the other localities. At temperatures of 25 and 30 ºC, there were no significant differences among the localities. At temperatures of 35 and 40 ºC, seeds from Bananeiras showed the highest speed of germination. In a study with the same taxon on substrate paper filter, Meiado et al. (2016), the temperature of 25 ºC with 12 hours of photoperiod germination was higher than 92% and at 30 ºC was higher than 80%.

Table 2. Variance analysis summary for the evaluated factors during germination and vigor tests on *Pilosocereus catingicola* seeds (Gurke) Byles & Rowley subsp. *salvadorensis* (WERDERM.) Zappi (Cactaceae).

Variation source	DF	MS	SS	F
		Germination		
Locality (L)	2	782.7222	1565.4444	23.5078 **
Temperature (T)	5	15017.6889	75088.4444	451.0318 **
L x T	10	1212.6556	12126.5556	36.4201**
Residue	54	33.2963	1798.0000	
CV (%)	10.44			

Variation source	DF	MS	SS	F
		GSI		
Locality (L)	2	62.7210	125.4419	19.3630 **
Temperature (T)	5	404.3651	2021.8257	124.8344**
L x T	10	80.8345	808.3447	24,9550**
Residue	54	3.2392	174.9175	
CV (%)	20.40			

NS, * e ** = Não-significativo, significativo a 5 e 1% de probabilidade, respectivamente, pelo teste F.
NS, *, and ** = non-significant, significant at 5%, and significant at 1% probability, respectively by the F test.

Table 3. Germination rate (%) and germination speed index (GSI) of *Pilosocereus catingicola* (Gurke) Byles & Rowley subsp. salvadorensis (Werderm.) Zappi (Cactaceae) seeds in the municipalities of Arara, Bananeiras, and Boa Vista – PB, Brazil. Uppercase letters compare temperatures at each location, and lowercase letters compare localities in each temperature.

	Temperatures	20	25	30	35	40	20-30
Germination	Arara	96Aa	92.5ABa	82BCa	5.5Db	11.5Db	79Ca
	Bananeiras	24.5Cc	96Aa	77Ba	26Ca	26Ca	81Ba
	Boa Vista	39.5Cb	92.5Aa	77Ba	4Db	4Db	81ABa
CV (%)	10.44						
GSI	Arara	10.7Ba	15.82Aa	5.8Cb	0.95Db	1.4Db	8.3Bc
	Bananeiras	3.5Db	11.35Bb	16.27Aa	7.425Ca	5.1CDa	18.7Aa
	Boa Vista	2.6Bb	15.4Aa	16.37Aa	0.6Bb	0.625Bb	17.9Aa
CV (%)	20.40						

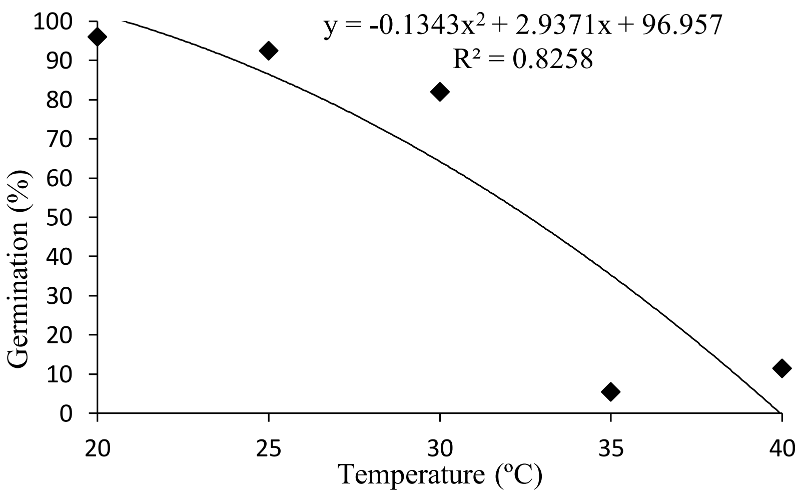
According to Lone et al. (2014), the constant temperatures of 25 and 30 ºC and the alternating temperatures of 20-30 ºC were adequate for the germination of pitaya seeds (Cactaceae), *Hylocereus undatus,* and for the hybrid *Hylocereus undatus* x *Hylocereus costaricensis*. Corroborating also with Abud et al. (2010), the facheiro seeds behaved as positively photoblastic at constant temperatures of 25 and 30 ºC, providing the highest germination rates and GSI values. Marcos Filho (2015) stated that the effects of light on positively photoblastic seeds are beneficial and drive the synthesis of hormones and enzymes, respiratory control, tegument permeability to oxygen, and lipid metabolism.

Table 3 shows that the GSI of seeds arising from Arara presented the highest vigor at 25 ºC (16.0), while for those from Bananeiras and Boa Vista the temperature was 30 ºC (16.27). When comparing the localities within each temperature, depending on the temperature used, one or more localities stand out. We could not state with certainty which location stood out in terms of producing seeds with greater vigor. At 30° C and at the alternating temperature 20-30 ºC, Bananeiras and Boa Vista stood out, while at 25° C, Arara did.

The highest germination rates were obtained at temperatures of 25 and 30 ºC (constant). The largest decrease was observed when the seeds were subjected to the highest temperatures, 35 and 40 ºC, regardless of the locality. Abud et al. (2012) claim that studies related to germination and viability of Cactaceae seeds native from the Northeast region are still scarce, and there are few in scientific literature. Seeds from different species present variable germinative behavior according to the temperature, which may provide information on biological and ecological interest (LABOURIAU, 1983).

Figure 3 shows the facheiro seeds' germination behavior from Arara. The data are fit to the quadratic polynomial regression model. The germination decreases with increasing temperatures. From 30 ºC on, a drastic fall occurs in the highest temperatures of 35 and 40 ºC. The germination rates were 96%, 92.5%, and 82% at temperatures of 20, 25, and 30 ºC, respectively, decreasing sharply at higher temperatures.

Figure 3. Germination rate of facheiro seeds from a natural population located in Arara, PB.



Temperature is an important factor able to restrict the occurrence of many species in certain ecosystems, preventing germination and establishment of the seedling under unfavorable conditions. Studies on the influence of temperature on seed germination are essential for the understanding of ecological and physiological aspects and the occurrence of species in natural environments (LABOURIAU, 1983; BEWLEY; BLACK, 1994).

Meiado et al. (2010) evaluated the germination of 30 taxa of Cactaceae collected in the Northeast region of Brazil. Among the temperatures tested by these authors, the alternating temperatures were less favorable for germination than were the constant ones. They also set as optimal for Cactaceae seed germination temperatures between 20 and 35 ºC.

Favorable temperatures for cactus seeds are between 15 and 35 ºC. For instance, Rojas-Aréchiga and Vásquez-Yanes (2000) concluded that the optimum temperature for germination of the seeds of Cactaceae was around 25° C. GUEDES et al. (2009) found that the use of paper roll as substrate proved to be more suitable for conducting seed germination and vigor tests on *Cereus jamacaru* DC at a temperature of 30 ºC. Abud et al. (2013) evaluated different temperatures in seeds of *Cereus jamacaru* DC from the State of Ceará; the best temperature for the germination of this species was 25 ºC.

The germination rates of seeds from both Bananeiras and Boa Vista were adjusted to a quadratic polynomial regression model (Figures 4 and 5). At 20ºC, only 24% seeds germinated; at 25 ºC, it reached a maximum of 96%; from 30 ºC onwards, the rate decreased. These outcomes evidence a deleterious effect of temperatures such as 35 and 40 ºC.

Figure 4. Germination rate of facheiro seeds from a natural population located in Bananeiras, PB.

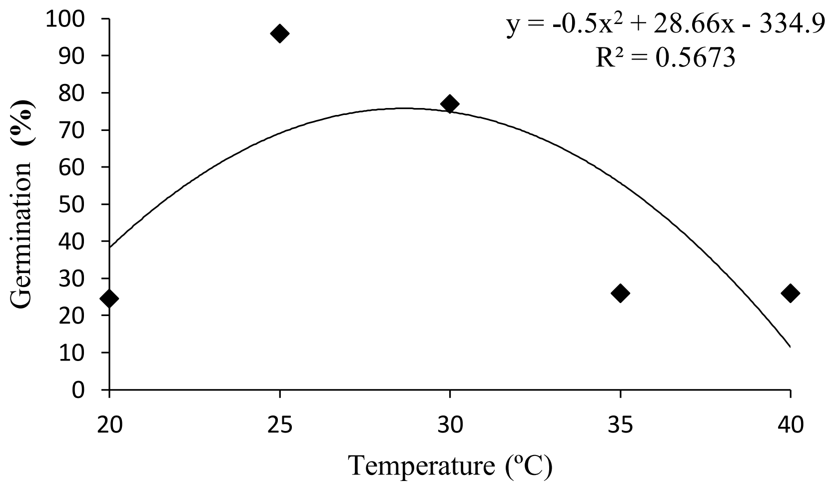


Figure 5. Germination rate of facheiro seeds from Boa Vista-PB and submitted to different temperatures. Bananeiras, PB, Brazil. 2015.

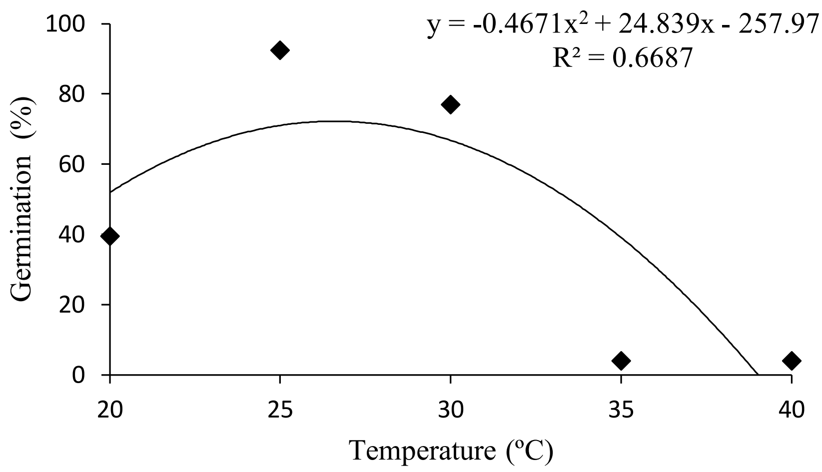


Figure 5 shows the facheiro seed germination from Boa Vista-PB. The data also adjusted to the quadratic polynomial regression model with the highest percentage (92.5%) of germination at 25 ºC, decreasing sharply at the highest temperatures, reaching 4%.

Guedes et al. (2009) studied the germination of *Cereus* jamacaru DC. subsp. *jamacaru* with seeds collected in the municipality of Boa Vista, State of Paraíba and obtained similar results with germination higher than 80% at temperatures of 25 and 30 ºC.

Regarding the germination speed index (Figures 6, 7, and 8), the data from the three localities adjusted to the quadratic polynomial regression model. Analyzing the localities of Bananeiras and Boa Vista (Figures 7 and 8, respectively); there is a continuous increase in germination speed index from 20 to 30 ºC when it reaches its maximum vigor. From this point, there is a sharp decrease in vigor for Boa Vista (Figure 8) at temperatures of 35 and 40 ºC. For the location of Arara (Figure 6), the germination speed index was also increasing up to 30 ºC; however, the highest GSI was reached at 20 ºC; this effect was not observed in the other localities. The germination and vigor data, evaluated by the germination speed index, differ according to the locality and temperature tested. Minimum and maximum temperatures affect the germination process of germination of seeds.

Figure 6. Germination speed index (GSI) of facheiro seeds from a natural population located in Arara, PB, Brazil.

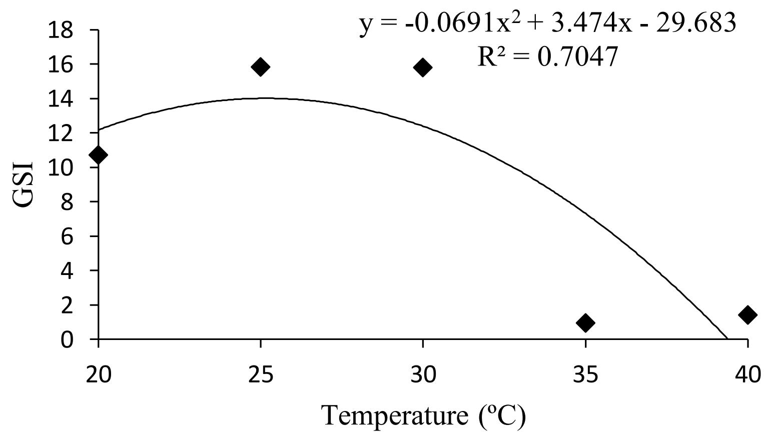


Figure 7. Germination speed index (GSI) of facheiro seeds from a natural population located in Bananeiras, PB, Brazil.

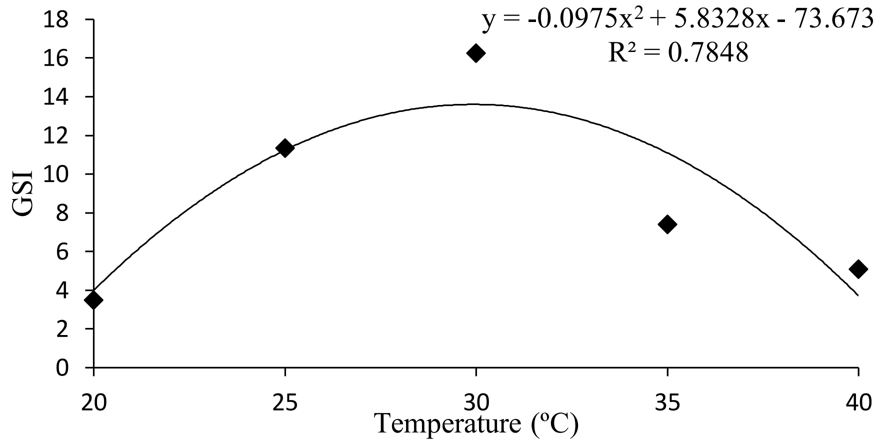
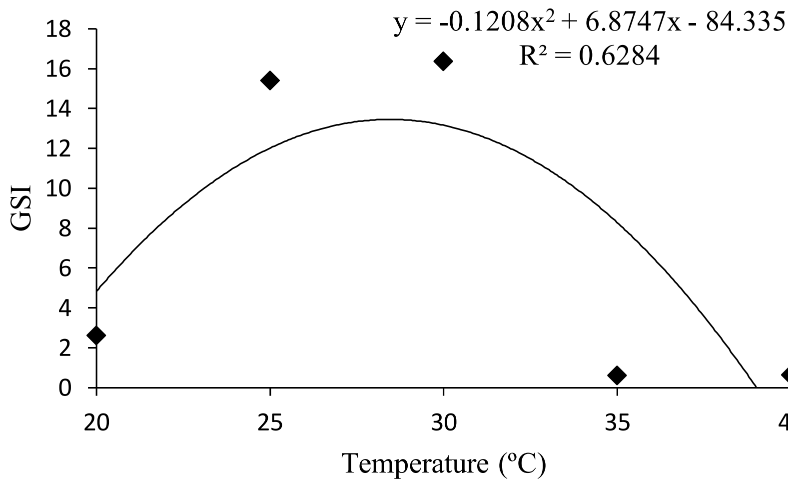


Figure 8. Germination speed index (GSI) of facheiro seeds from a natural population located in Boa Vista, PB, Brazil.



Baskin and Baskin (2001) mentioned that temperatures below or above the optimum range tend to reduce the germination speed, causing the seeds to be exposed for a longer period to adverse factors, which may lead to a reduction in total germination. This may explain the inferior performance obtained by the facheiro seeds when subjected to the high temperatures of 35 and 40 ºC, as well as the low temperature of 20 ºC (except for the locality of Arara). Medeiros et al. (2015), who the same species with seeds from the municipalities Arara, Areial, and Boa Vista in the state of Paraíba, obtained a germination speed index of 7.1 with alternating temperatures of 20-30ºC and a constant temperature of 30 ºC. Regarding the species *Pilosocereus pachycladus,* Abud et al. (2010) obtained a germination speed index of 7.0 at a temperature of 30 ºC and 4.3 with a temperature of 20-30 ºC. According to these authors, the constant temperatures of 25 and 30 ºC provided the highest percentages and speeds of germination of facheiro seeds.

Conclusion

The species showed a high germination rate at constant temperatures of 25 and 30 ºC and at an alternating temperature of 20-30 ºC in the three studied areas. In general, the highest germination speed was obtained at temperatures of 25, 30, and 20-30 ºC.

For the studied localities, the taxon in question has the ability to survive in environments with temperatures ranging from 20 to 30 ºC regarding its sexual propagation.

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