

Effects of water deficit and pH on seed germination and seedling development in *Cereus jamacaru*

Déficit hídrico e pH na germinação de semente e no desenvolvimento de plântula de *Cereus jamacaru*

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Abstract

The lack of water and soil acidity are current problems occurring in many regions around the globe. Therefore, it is essential to investigate the effects of seed germination and seedling development, in order to determine the species adaptability to the ever-changing environment. The aim of this study was to evaluate the effects of water deficit and pH on seed germination and seedling development in *Cereus jamacaru*. A completely randomized experiment was performed. A factorial scheme of 6×7 , corresponding to six osmotic potential values (0.0, -0.2, -0.4, -0.6, -0.8, and -1.0 MPa) induced by PEG 6000, and seven pH levels (3, 4, 5, 6, 7, 8, and 9) with four replications was used. The variables analyzed were germination (G), germination speed index (GSI), mean germination time (MGT), normal seedling (NS), root length (RL), shoot length (ShL), seedling length (SL), and seedling dry mass (SDM). The statistical analysis included ANOVA and binomial models (G and NS), regression models with quadratic terms (GSI and MGT), and response surface method (ShL and SL) for the variables with at least one significant factor ($p < 0.05$). *C. jamacaru* showed susceptibility to water deficit at seed germination and seedling development stages, indicated by the decreases in G, GSI, NS, ShL, and SL at osmotic potential below to 0.0 MPa. The pH interaction with osmotic potential affected *C. jamacaru* seedling development. The increase in pH was favorable for seedling development, but not for seed germination. **Key words:** Cactaceae. Osmotic potential. Acidity. Polyethylene glycol. Viability. Vigor.

Resumo

A falta de água e a acidez do solo já são problemas enfrentados em várias regiões do planeta. Por esta razão, torna-se imprescindível estimar ambos fatores no processo de germinação de semente e no desenvolvimento de plântula, a fim de determinar a adaptabilidade das espécies às mudanças das condições ambientais. O objetivo deste estudo foi avaliar os efeitos do déficit hídrico e do pH no processo germinativo e no desenvolvimento de plântula de *Cereus jamacaru*. Para o estudo, utilizou-se o delineamento experimental inteiramente casualizado, em esquema fatorial 6×7 , correspondente a seis valores de potencial osmótico (0,0; -0,2; -0,4; -0,6; -0,8 e -1,0 MPa), induzidos por PEG 6000, e sete níveis de pH (3, 4, 5, 6, 7, 8 e 9), com quatro repetições. As variáveis analisadas foram germinação (G), índice de velocidade de germinação (IVG), tempo médio de germinação (TMG), plântula normal (PN), comprimento de raiz (CR), comprimento de parte aérea (CPA), comprimento de plântula (CP) e massa seca de plântula (MSP). A análise estatística incluiu análise de variância e modelos binomiais (G e PN), modelos de regressão com termos quadráticos (IVG e TMG), e método de superfície de

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resposta (CPA e CP) para as variáveis com pelo menos um fator significativo ($p < 0.05$). A espécie *C. jamacaru* mostrou-se suscetível ao déficit hídrico em ambos os estágios fisiológicos: germinação de semente e desenvolvimento de plântula; dado o fato da redução da G, IVG, PN, CPA e CP em potenciais osmóticos inferiores a 0,0 MPa. O pH em interação com o potencial osmótico afetou o desenvolvimento de plântula de *C. jamacaru*. O aumento do pH foi favorável para o desenvolvimento de plântula, porém foi indiferente para a germinação de semente.

Palavras-chave: Cactaceae. Potencial osmótico. Acidez. Polietilenoglicol. Viabilidade. Vigor.

Introduction

The Cactaceae family (succulent plants) is usually cultivated in arid and semi-arid regions, due to their low demand for water and fertilizers. These species are used for food and fodder, sustainable development (mainly during the long periods of drought, common in many areas), and for sustainability and conservation of biomes (CAVALCANTI; RESENDE, 2007).

Cereus jamacaru DC. is a Cactaceae native from Caatinga (Brazil). It bears fruits between February and August. The tree is arboreal, with a height of 3 to 10 m, columnar canopy, multi-branched trunk, strong broadside article fittings, and hard thorns, from gray to golden, in different numbers and sizes. The flowers are big, white, and numerous, reach anthesis at night time, and are pollinated by moths and bats, from January to August. Fruits are berry-like, oblong, dehiscent, and large (from 10 to 13 cm long) with glabrous epicarp from pinkish to red, and produce edible, fleshy, white, and semi-acidic pulp with numerous small, black, and insipid seeds (LIMA, 1996; ROCHA; AGRA, 2002).

This species has the capacity for vegetating in extremely poor, shallow, and stony soils, and can endure several months of drought, when it is used for livestock feeding (SILVA; ALVES, 2009). It is also used for ornamental purpose (LIMA, 1996), especially for plant epidermis staining and/or its exoticism (RIZZINI et al., 1988).

The main form of reproduction of *C. jamacaru* is vegetative, although sexual reproduction is extremely important for breeding enhancement, considering the genetic diversity that occurs within

this process. Due to these characteristics, the study of germination in this species is justified, as there are no data available in the Rules for Analysis of Seeds (BRASIL, 2009; GUEDES et al., 2009).

Plants are subjected to stressful conditions that limit their development, which demands knowledge on how those stresses influence seed germination. Such stress conditions are important for the ecophysiology when evaluating the limits of tolerability and the adaptation capability of species (LARCHER, 2000). The germination ability of the seed under conditions of drought stress provides ecological benefits in relation to seeds that are sensitive to drought (ROSA et al., 2005).

The ability of adapting under stressful conditions leads – or gives a way – to integrated events that occur at various levels, including morphological, anatomic, cellular, biochemical, and molecular alterations. Water deficit is one of the main limiting factors to seed germination, since water triggers this process besides being involved, directly or indirectly, in all the subsequent phases of the plant metabolism (MARCOS FILHO, 2015).

Water deficit generally reduces the uniformity, speed, and percentage of seed germination (ROSA et al., 2005), affecting both cell elongation and cell wall synthesis (CARVALHO; CASALI, 1999). Furthermore, water deficit can provoke restriction in the acquisition of nutrients and water, which affects seedling formation (MANIVANNAN et al., 2008; MARCOS FILHO, 2015) and causes oxidative stress in some species (JALEEL et al., 2007).

The soaking process depends on the water gradient potential (water tension) between the seed

and the external medium (ÁVILA et al., 2007). For each species, there is a critical water potential value, below which the germination process does not occur (MARCOS FILHO, 2015). The minimal moisture content level the seed has to reach to enable germination depends on both the seed chemical composition and permeability of the seed coat (CARVALHO; NAKAGAWA, 2012).

Therefore, studies of seed germination response under artificial stress conditions can help to better understanding the survival and adaptation capability of plant species under natural stress conditions (PEREIRA et al., 2012). For this purpose, some methodologies have been developed and recommended to determine plant tolerance to water stress; the most frequently used method is the observation of the ability of seeds to germinate under those conditions (LARCHER, 2000).

Therefore, studies have been conducted using solutions with different osmotic potential, applying humidifying substrates (usually paper). The seeds are sowed for germination, in an attempt to simulate water stress, to determine the tolerance point to drought among different species. Those studies aimed to simplify the complex conditions observed in field or greenhouse conditions. Consequently, another option is the use of watery solutions of polyethylene glycol (PEG) as the osmotic agent, since it is not easily metabolized by living organisms and, when at high molecular weight (>4000), does not present adverse effects for the seeds because it does not penetrate into the cells, does not cause toxicity, and is not degradable (MEXAL et al., 1975; SANTOS et al., 2008).

Another soil property that affects seed germination is the concentration of hydrogen ions, which is expressed in pH. The soil pH can influence plants in two ways: either by direct influence from hydrogen ions when at extreme pH values, or by indirect influence, affecting the assimilation of a number of nutrients as well as turning soluble some of toxic elements (BRADY; WEIL, 2013).

According to the Rules for Analysis of Seeds (BRASIL, 2009), for most species, it is recommended that the pH, both in substrate and water, should be between 6.0 and 7.5. This is in line with the study by Kerbauy (2008), who verified the effect of pH on seed germination and seedling development in extremely acidic and alkaline environments. Besides, according to Kerbauy (2008), the pH range of 6.0 to 7.5 was perceived as ideal for germination of most vegetable species, ensuring better vegetable biochemical processes and nutrition (LARCHER, 2000).

Evaluation of effects of water and pH on both seed germination and seedling development can provide important data on the tolerance of a species to dry and/or acidic soils. This allows the adoption of suitable control and integrated management practices. Thus, the aim of this study was to evaluate the effects of water deficit and pH on seed germination and seedling development in *C. jamacaru*.

Material and Methods

This experiment was performed at the Seed Technology and Production Laboratory at Londrina State University (UEL), Londrina-PR (Brazil). The seeds were obtained from the *C. jamacaru* ripe fruit and cultivated in an experimental area belonging to the UEL Agronomy Department (23°23' S, 51°11' W at an average height of 566 m). Fruits were longitudinally sectioned; pulp and seeds were extracted with a spoon and incubated in a solution of water (1 L) and sucrose (25 g L⁻¹) for 48 h at room temperature, to facilitate fermentation and seed extraction. After the incubation period, the solution was sieved under running water to eliminate pulp residues and preserve the seeds. Thereafter, they were placed in a filter paper and dried in shade at room temperature for 48 h (ORTIZ et al., 2015).

For this study, six osmotic potential values (0.0, -0.2, -0.4, -0.6, -0.8, and -1.0 MPa) and seven pH

levels (3, 4, 5, 6, 7, 8, and 9) were evaluated in a 6×7 factorial scheme, in a completely randomized experimental design with four replications.

For the preparation of the solution, aiming to achieve the osmotic potential, distilled water and polyethylene glycol 6000 (PEG) were used according to the methodology described by Braccini et al. (1998). The pH of the solution was adjusted using hydrochloric acid (HCl) and sodium hydroxide (NaOH), and measured with the aid of a pH-meter Jenway, model 3510®.

The physiological quality of the seeds was evaluated by using the germination test, for which 50 seeds were used, by replication. The seeds were placed in crystal polystyrene boxes (Gerbox® type) lined with a sheet of blotting paper, with the solutions related to each treatment at 2.5-fold the mass of the substrate. The experiment was performed in a germinator at a constant temperature of 25 °C and 24-h photoperiod, using a fluorescent lamp.

The variables analyzed were: germination (G – expressed in percentage), germination speed index [GSI – calculated according to the methodology of Maguire (1962)], and mean germination time [MGT – expressed in days, according to Lima et al. (2006)]. The evaluation was performed on a daily basis, for 21 days, when the stabilization of the germination process occurred. The seed was considered as germinated when it presented radicle elongation equal to or above 0.2 cm.

Furthermore, on day 21 after the experiment installation, on the following variables were also assessed: normal seedling (NS – expressed in percentage, taking into account only the seedlings having a length equal to or greater than 1 cm), root length (RL – expressed in cm per seedling, data obtained by measuring all root of normal seedlings in each treatment, with the aid of a graduated scale in mm), shoot length (ShL – expressed in cm per seedling, data obtained by measuring all shoot of normal seedlings in each treatment), seedling length (SL – expressed in cm per seedling, determined

by measuring the normal seedlings total length, from the root base up to the apex of the shoot), and seedling dry mass [SDM – expressed in g per seedling, determined by packaging all normal seedlings in each replication in identified paper bags, which were placed in a lab oven until constant weight was attained. Then, the samples were placed in a dissector for about 2 h, to be cooled, and further weighed on a digital analytic scale (Shimadzu, model AW 320®)].

Statistical analyses were performed using the software R (R DEVELOPMENT CORE TEAM, 2019). The variance analysis was performed with further adjustment of regression models for variables with at least one significant factor ($p < 0.05$). The variables G and NP were fitted using binomial models, because the response variable is a percentage (proportion). Adjustments of the regression models with quadratic terms were conducted for the variables GSI and MGT, because only the osmotic potential factor was significant. For the variables ShL and SL, two factors (osmotic potential and pH) were significant. Therefore, they were analyzed by using the response surface method. Nevertheless, none of these factors were significant for the variables RL and SDM ($p < 0.05$).

Results and Discussion

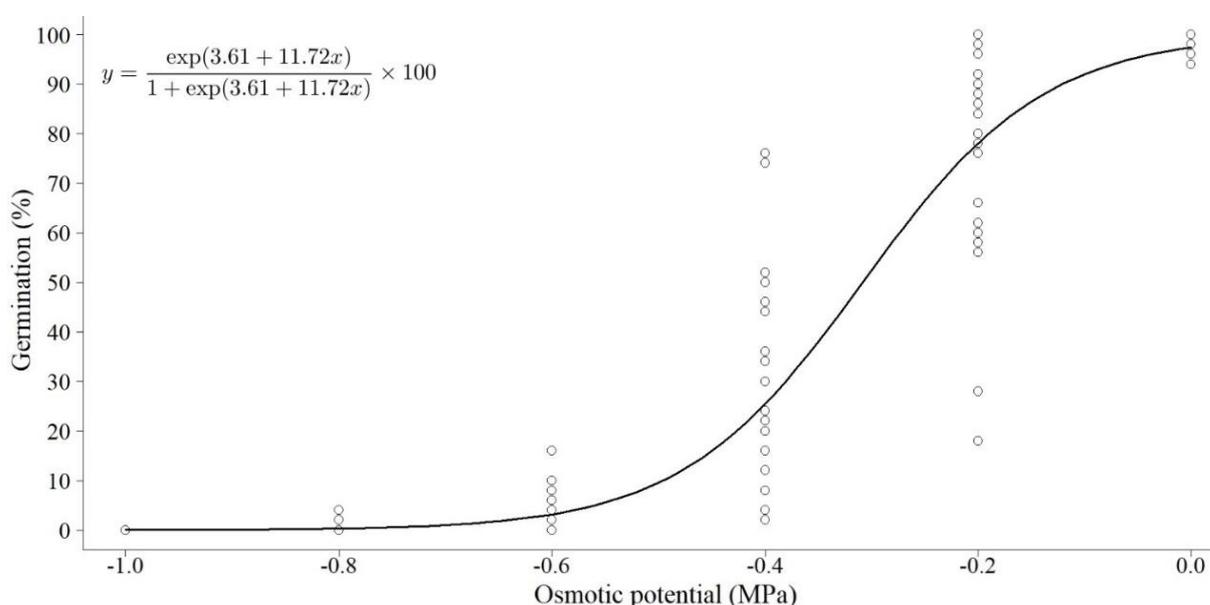
Cereus jamacaru seed germination did not present any statistical differences in the pH (data not shown). Similar findings were also observed by Ortiz et al. (2015) in three *Hylocereus* genotypes (Cactaceae) and Wandscheer et al. (2011) in *Lactuca sativa*. Tolerance to pH is species-dependent; seed germination in some plant species, such as *Emilia sonchifolia*, is affected by the pH (YAMASHITA et al., 2009), but *C. jamacaru* showed no response to pH changes.

The osmotic potential influenced *C. jamacaru* seed germination, with a downward trend under decreasing osmotic potential [maximum point ($x = 0.0$) and minimum point ($x = -1.0$)]. The percentage

of germination was reduced, in average, from 98.57% at 0.0 MPa to 75.26%, 27.33%, 2.86%, 0.36%, and 0.00% at -0.2, -0.4, -0.6, -0.8, and -1.0 MPa, respectively (Figure 1). Therefore, this shows the susceptibility of this species to water deficit, with attenuation of the adverse response at osmotic potential lower than -0.2 MPa. Ortiz et al. (2014) also observed a gradual decrease in *Hylocereus* spp. germination under osmotic potential induced by PEG 6000, resulting in germination percentage

of approximately zero when the osmotic potential was lower than -0.6 MPa. Nevertheless, some authors found a linear relationship between seed germination and osmotic potential, with a lower tendency of germination at low osmotic potential, such as in *Sorghum bicolor* (OLIVEIRA; GOMES-FILHO, 2009), *Urochloa ruziziensis* (MASETTO et al., 2013), and *Senna obtusifolia* (PEREIRA et al., 2014).

Figure 1. Germination (%) of *C. jamacaru* seed (y) as a function of the osmotic potential (x).



Yamashita and Guimarães (2010) also observed a significant reduction in germination in *Coryza* spp. from -0.2 MPa, although there was a decrease of more than 50% relative to the control, at -0.4 MPa. This corroborates the result obtained in this study, in which *C. jamacaru* species presented a germination reduction superior to 70% at -0.4 MPa. Yamashita et al. (2009) showed a more abrupt germination reduction in *E. sonchifolia* with decreasing osmotic potential, from 92% at 0.0 MPa to 22% and 9% at -0.1 and -0.2 MPa, respectively. No germination occurred at osmotic potential equal to or less than -0.4 MPa.

Other authors also observed that the germination percentage tends to decrease with decreasing osmotic potential. This indicates that, at a determined gradient, the seeds become unable to complete the germination process, as observed by Lima and Torres (2009) in *Ziziphus joazeiro* at -0.9 MPa, Martins et al. (2011) in *Melaleuca quinquenervia* at -0.8 MPa, Pereira and Lopes (2011) in *Jatropha curcas* at -1.2 MPa, Santos et al. (2011) in *Genipa americana* at -0.3 MPa, Pereira et al. (2012) in *U. decumbens* and *U. ruziziensis* at -0.8 MPa, and Pereira et al. (2014) in *S. obtusifolia* at -0.8 MPa. In the present study, *C. jamacaru* seeds

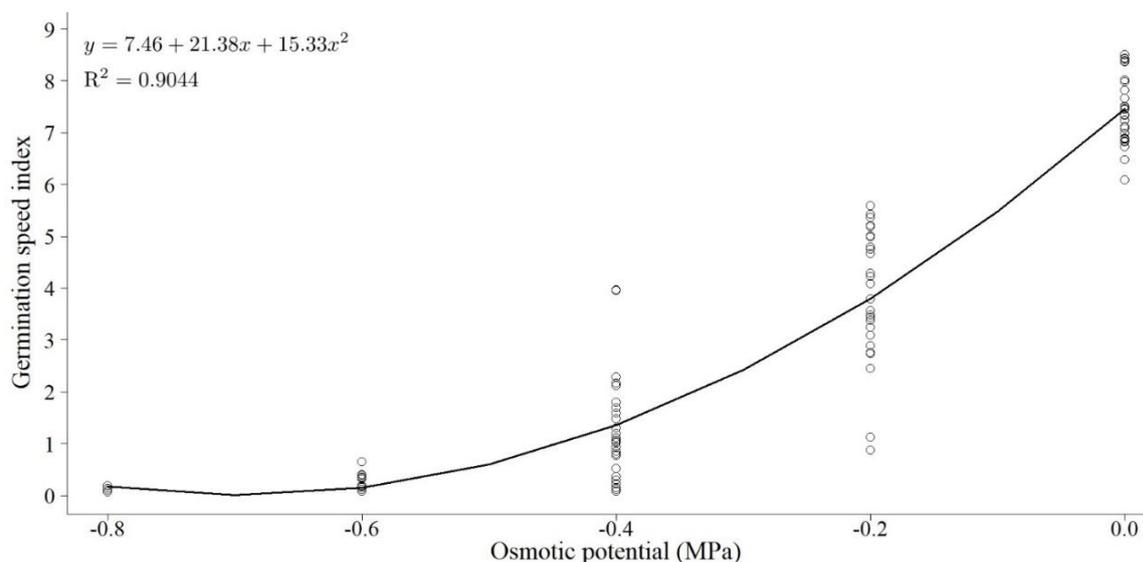
did not germinate only at -0.1 MPa, despite the low germination percentage under the osmotic potential of -0.6 and -0.8 MPa.

These results can be justified by the fact that, once the seeds are in contact with aqueous solutions containing solutes, water soaking starts naturally and ceases as the osmotic potential of the seed becomes equal to that of the external solution. In relation to the germinating seed, it has to attain a minimum moisture content, which is variable among the species; when the solution osmotic potential is low, there will be impediment for expansion of the primary root, even when the seed contains adequate water content to enable physiologically activity,

mobilize its reserves, and start its germination process. The seed will cannot reach the cell elongating phase after some weeks of contact with the osmotic solution (FONSECA; PEREZ, 2003).

There was influence of the osmotic potential (MPa) in the *C. jamaicaru* germination speed index (GSI), which showed quadratic behavior with a downward trend under decreasing osmotic potential (Figure 2). However, GSI was not affected by pH (data not shown). Ortiz et al. (2015), working with cacti species, also observed that the GSI did not present any statistical differences at pH levels for two out of three *Hylocereus* genotypes.

Figure 2. Germination speed index of *C. jamaicaru* seed (y) as a function of the osmotic potential (x).



Regarding the osmotic potential factor, it can be observed that the GSI tends to decline when the osmotic potential decreases up to -0.697 MPa, when the minimum point is achieved. However, Oliveira and Gomes-Filho (2009), while evaluating this variable in *S. bicolor*, observed a linear behavior with a decreasing tendency with declining osmotic potential from 0.0 to -0.8 MPa, for both evaluated genotypes.

In the present study, the gradient of -0.6 MPa showed lower indexes, while the peak occurred

at 0.0 MPa (maximum point) (Figure 2). Various authors also observed a decreasing tendency of the GSI with decreasing osmotic potential; for example Lima and Torres (2009) in *Z. joazeiro*, Yamashita et al. (2009) in *E. sonchifolia*, Santos et al. (2011) in *G. americana*, Pereira et al. (2012) in *U. decumbens* and *U. ruzizensis*, Pereira et al. (2014) in *Raphanus raphanistrum* and *S. obtusifolia*, and Ortiz et al. (2014) in *Hylocereus* spp.

Martins et al. (2011) found significant differences in GSI at all osmotic potential values

assessed in *M. quinquenervia*, where they obtained GSI values of 9.37, 7.86, and 3.09, at 0.0, -0.2, and -0.4 MPa, respectively. At osmotic potential of -0.8 MPa, GSI was not calculated due to failure of seed germination. This was in line with the present study, as GSI was also not calculated at -1.0 MPa due to the non-existence of germinated seeds of *C. jamacaru* at osmotic potential lower than -0.8 MPa.

Pereira and Lopes (2011) showed that GSI in *J. curcas* decreased by more than 10 gradient units from 0.0 to 0.2 MPa, reaching values of approximately zero at -0.8 MPa. Yamashita and Guimarães (2010) showed a significant reduction in germination speed in *Conyza* spp. seed, which decreased from 13.97 at 0.0 MPa to 6.68 at -0.2 MPa and 2.41 at 0.4 MPa, achieving values of approximately zero or equal to zero at osmotic potential of -0.6, -0.8, and -1.0 MPa. This corroborates the results obtained in *C. jamacaru*. This behavior is possibly explained by the reduction in the speed of metabolic and biochemical processes due to water restriction, which either delays or reduces seed germination and interferes with the embryo soaking and cell elongation.

For the mean germination time (MGT, in days), there was also no influence of the pH factor, as indicated by the germination percentage and germination speed index (data not shown). Wandscheer et al. (2011) studied the germination speed (in days) of *L. sativa* seed and also observed that there was no significant difference in the germination speed due to the assessed treatments (pH levels from 3 to 11). Nevertheless, Ortiz et al. (2015) found a pH effect on the MGT of two *Hylocereus* genotypes.

The MGT presented statistical differences in the osmotic potential, displaying a quadratic behavior. The MGT showed an increase when, at 0.0 MPa, seed germination occurred after 6.88 days, increasing to 10.41 days at -0.2 MPa and 11.60 days at -0.4 MPa, followed by a decrease in the osmotic potential from

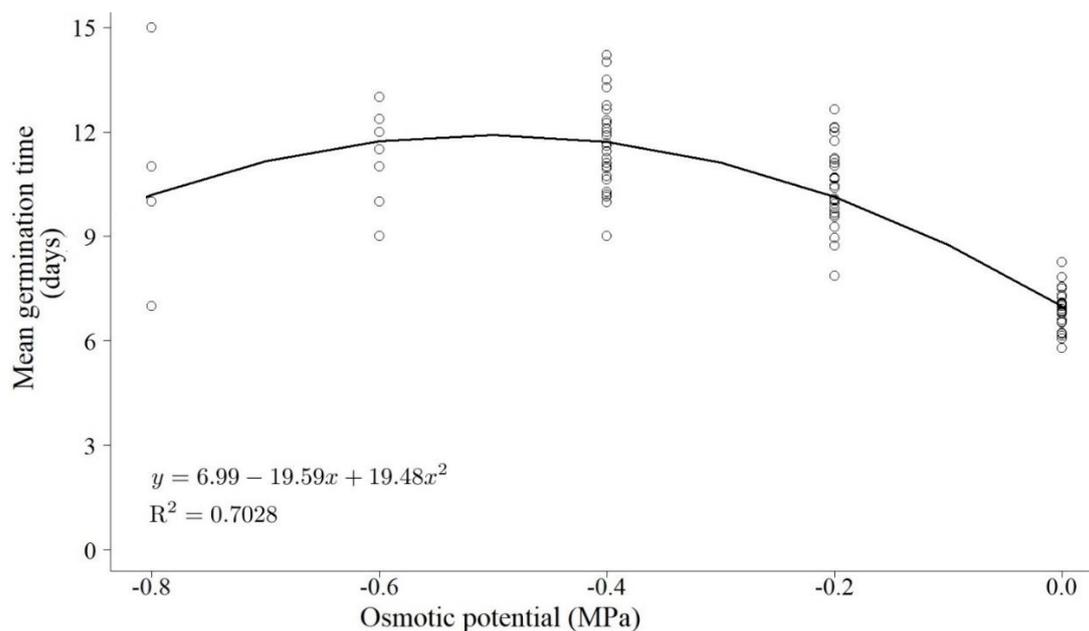
-0.6 and -0.8 MPa, at which the *C. jamacaru* seeds germinated after 11.49 and 10.75 days, respectively. The maximum point was obtained at -0.5028 MPa, while the minimum point was observed at 0.0 MPa (Figure 3). The MGT was not calculated for osmotic potential up to -1.0 MPa, due to failure of seed germination at osmotic potential below to -0.8 MPa.

In the study by Pereira and Lopes (2011), the MGT increased with decreasing osmotic potential. The authors showed that *J. curcas* seed required approximately 3 days for germination at 0.0 MPa, but required 5 and 9 days at osmotic potential of -0.2 and -1.0 MPa, respectively. This highlights potential problems for the culture under field conditions, due to increased exposure period of seeds to the soil, adverse weather conditions (such as drought), pests, and other factors that can contribute to the decrease of the quality of the seeds.

Oliveira and Gomes-Filho (2009) evaluated the MGT of two *S. bicolor* genotypes and observed a linear relationship, with a crescent tendency with osmotic potential decreasing from 0.0 to -0.8 MPa. Similar findings were obtained by Santos et al. (2011) in *G. americana* and Ortiz et al. (2014) in *Hylocereus* spp., who showed that a larger water deficit, created by the increase of the concentrations of PEG 6000 in the substrate solution, significantly increased the mean germination time.

According to Oliveira and Gomes-Filho (2009), reduced seed metabolism is due to lower availability of water for the digestion of the reserves and the translocation of the metabolized products. Bewley and Black (1994) and Marcos Filho (2015) also suggests that the hydric stress can reduce both the percentage and speed of germination. These responses vary among species, ranging from very sensitive species to more resistant species. Thus, resistant seeds have ecological advantage when establishing seedlings in areas where the seeds sensitive to drought are not capable of establishing.

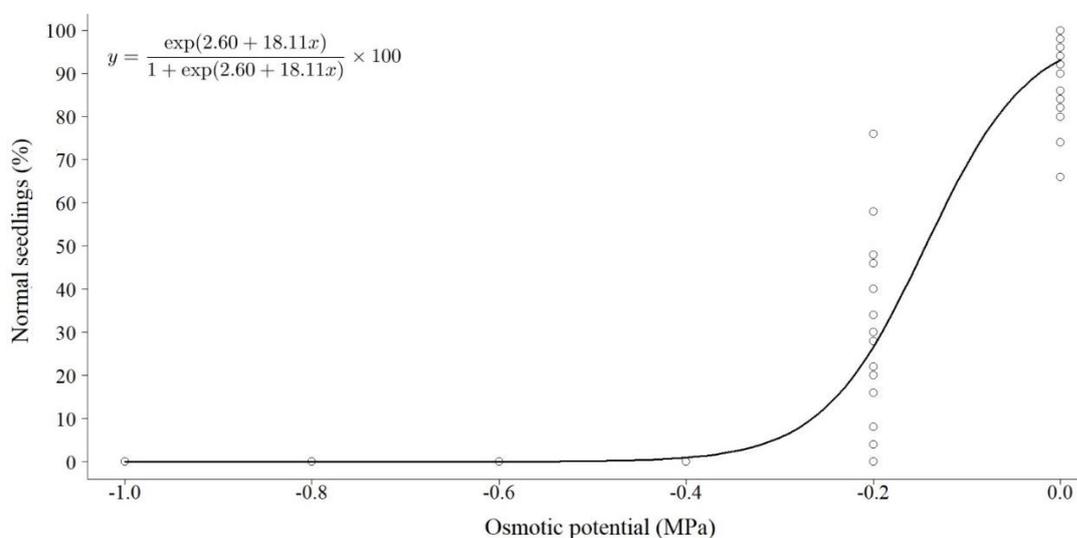
Figure 3. Mean germination time (days) of *C. jamaru* seed (y) as a function of the osmotic potential (x).



The pH also did not affect the percentage of normal seedlings (NS) of *C. jamaru* (data not shown), but the normal seedling variable was fitted to binomial model, despite that it did not develop at osmotic potential lower than -0.2 MPa (Figure 4). Therefore, the water deficit is extremely

unsuitable for seed development, when one takes into consideration the initial development of that species. There was an average of 92% of normal seedlings at 0.0 MPa and only 29% at -0.2 MPa, showing a decrease of approximately 70%.

Figure 4. Normal seedling (%) of *C. jamaru* seed (y) as a function of the osmotic potential (x).



Results reported by Moterle et al. (2008) support those of the present study; the authors showed a significant decrease in the percentage of strong normal seedling, in 11 out of 14 simple hybrids of *Zea mays*. This decrease varied from about 16% to 74% from 0.0 to -0.3 MPa, respectively. Moraes et al. (2005) also found a decrease in normal seedlings of *Phaseolus vulgaris* with decreasing osmotic potential (from 0.0 to -0.3 MPa).

The root length (RL) of *C. jamacaru* seedling did not show significant difference neither with pH levels nor with osmotic potential (MPa) (data not shown). Nevertheless, Wandscheer et al. (2011) observed a significant effect of pH on the root length of *L. sativa* seedlings.

In relation to the osmotic potential, some authors observed the influence of this factor on the root length, reporting reduced root length caused by the reduction of the osmotic potential solution; for example Moterle et al. (2008) in *Z. mays*, Masetto et al. (2011) in *Crambe abyssinica*, Pereira and Lopes (2011) in *J. curcas*, and Masetto et al. (2013) in *U. ruziziensis*. However, Vieira et al. (2013) observed that, in some *Glycine max* cultivars, the root length did not show significant differences among the osmotic potential values assessed.

Root development varies widely among plant species. This, according to the adaptation hypothesis, is either due to root proliferation that increases the nutrients absorption under competition situation, or related to the growth rate of the plant (KEMBEL et al., 2008).

Carneiro et al. (2011) observed that root length and root dry mass in *Helianthus annuus* was superior at osmotic potential of -0.2 and -0.4 MPa compared to 0.0 MPa, with a significant reduction at -0.8 MPa. This is in line with the study by Yoshimura et al. (2008), who reported that many proteins, which are induced at the initial stages of water stress, are also involved in root morphogenesis and the carbon/nitrogen metabolism. Thus, increased root growth can contribute to the prevention of stress. However,

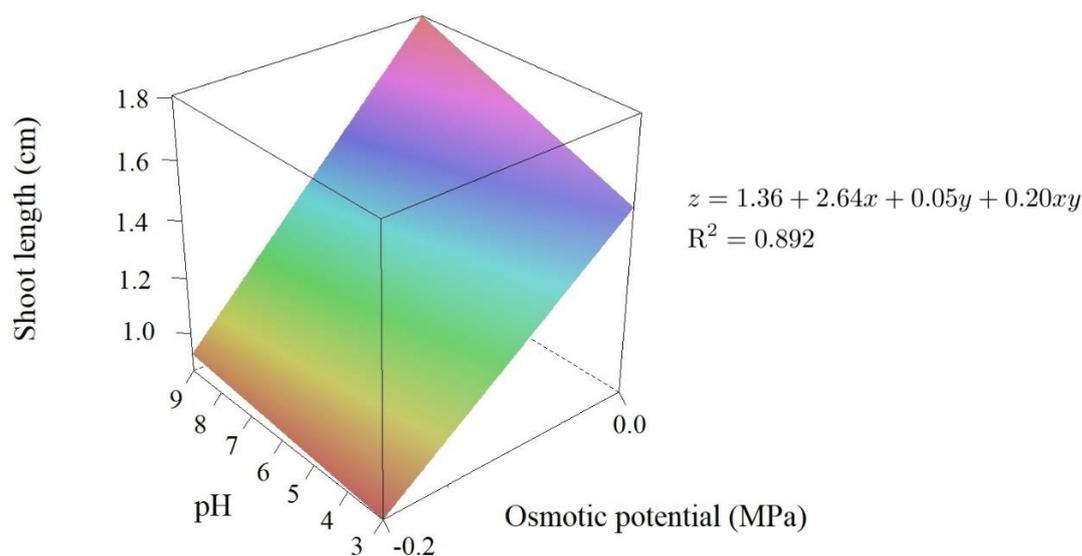
it is worth emphasizing that each plant species has a specific behavior and that Yoshimura et al. (2008) carried out the study with a species which exhibits high drought resistance (xerophyte).

According to Taiz and Zeiger (2013), increase in root development of seedlings subjected to water stress occurred as a defense mechanism, with greater development of the root system to favor the absorption of water from deeper depths. It can be observed that the osmotic potential affects the seedling root length in a different way for each species, as some species develop greater root length when the osmotic potential decreases; some species show reduced root length with increasing water deficit. There are other species such as *C. jamacaru*, the species investigated in the present study, are not affected by osmotic potential.

There was significant interaction effect between the osmotic potential and pH on shoot length (ShL) of *C. jamacaru* seedlings. Besides, both factors showed a linear variation (Figure 5). Shoot length decreased when the osmotic potential decreased from 0.0 to -0.2 MPa, and when the pH level decreased from 9 to 3. Therefore, the maximum and minimum points were reached at 0.0 MPa (x)/pH 9 (y) and -0.2 MPa (x)/pH 3 (y), respectively. This shows that the seedlings development better under a basic medium, taking into consideration the decrease due the acidity, besides the potential harmful effect of the water deficit.

Similar results were found by Masetto et al. (2011); they observed that the shoot length of *U. ruziziensis* seedling was negatively influenced by the reduction of water availability in the substrate, showing a linear relationship. This was also reported by other authors, such as Lima and Torres (2009) in *Z. joazeiro*, Carneiro et al. (2011) in *H. annuus*, Masetto et al. (2011) in *C. abyssinica*, Pereira and Lopes (2011) in *J. curcas*, and Vieira et al. (2013) in five *G. max* cultivars, who observed a decreasing tendency with increasing water deficit.

Figure 5. Surface response for the shoot length (cm) of *C. jamararu* seed (z) as a function of the osmotic potential (x) and pH (y).



Moterle et al. (2008) conducted a study using *Z. mays* simple hybrids and observed a decrease of up to 79% of shoot length when the medium osmotic potential was decreased from 0.0 to -0.3 MPa. Such an effect can be attributed to the fact that, under severe water deficit, the seedling can be affected as a whole, reducing its growth. Santos et al. (2012) concluded that the decrease in the shoot length in *B. napus* occurred due to the water restriction influence on the speed of the physiological and bio-chemical processes, limiting seedling development.

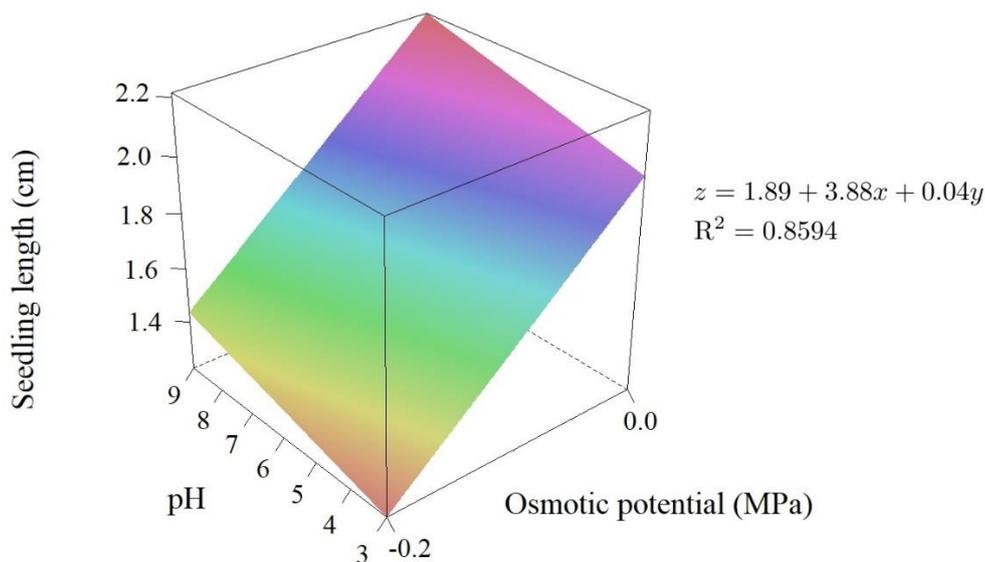
Seedling length (SL) of *C. jamararu* was not significantly affected by the interaction between the osmotic potential and pH. However, both osmotic potential and pH individually significantly affected the SL, presenting a linear relationship (Figure 6). For pH, there is a tendency of reduction in the SL (linearly) with the acidification of the environment (lower pH). For seedling length, the maximum and minimum points were reached at 0.0 MPa (x)/pH 9 (y) and -0.2 MPa (x)/pH 3 (y), respectively.

Figures 5 and 6 show that the axis gradient for osmotic potential varied only from 0.0 to -0.2 MPa,

due to the absence of normal seedlings at subsequent gradients. Due to the decrease in the osmotic potential from 0.0 to -0.2 MPa, the seedling length was also reduced (Figure 6), in line with Masetto et al. (2013). The authors showed negative effects of decreased water potential on the growth of *U. ruziziensis* seedlings, with a linear relationship. Moraes et al. (2005), Pereira and Lopes (2011), and Vieira et al. (2013) also observed a decreasing tendency of seedling length in *P. vulgaris*, *J. curcas*, and *G. max*, respectively, due decreasing osmotic potential.

Besides the water stress having a negative influence on the soaking, speed, and percentage of germination, Taiz and Zeiger (2013) also reported that the first measurable effect of the decrease in osmotic potential is the decrease in seedling growth, due to less water absorption by the seed, which results in the reduction of the rates of physiologic and biochemical processes, as a consequence of the decrease in cell expansion, which requires an appropriate potential turgor.

Figure 6. Surface response for the seedling length (cm) of *C. jamacaru* seed (z) as a function of the osmotic potential (x) and pH (y).



Both the cell elongation process and cell wall synthesis are very sensitive to water stress. According to Yasseen and Alomary (1994), reduced plant growth can be caused by a decrease in the turgidity of cells, presenting a negative effect mainly at the initial phase of the cell expansion, due to the reduction of the protein synthesis under water stress conditions (DELL'AQUILA, 1992). Therefore, the seedling developing under this medium, with a lower degree of humidity, presents a decrease in growth, characterized by lower seedling length (MOTERLE et al., 2008).

Seedling dry mass (SDM) of *C. jamacaru* was not significantly affected by both pH and osmotic potential (data not shown).

As observed in the present study in *C. jamacaru*, each of the variables assessed can be influenced or not, to a greater or smaller degree, by factors such as osmotic potential and pH. Similar studies need to be conducted in different species and regions.

According to studies by Mizrahi et al. (1997), cacti are generally tolerant to water stress. Nevertheless, to state species tolerance and/or susceptibility of a plant species to water stress, it has to be taken

into account its physiological stage. In view of this, despite the representatives of the Cactaceae family being mostly cultivated in arid and semi-arid regions, the species *C. jamacaru* has proved to be susceptible to water deficit when evaluating the seed germination and seedling development stages. Taking into consideration that the reduction in water availability simulated by PEG osmotic solutions was prejudicial to the germination process of the seed and the growth of the seedling, it was concluded that the variables G, GSI, NS, ShL, and SL presented decreasing tendency with decreasing osmotic potential.

Furthermore, due to the decrease of the osmotic potential, the germination process demands more time to occur, which is a disadvantage if we consider the actual field conditions, when the seeds would be susceptible to possible unfavorable edaphic climatic conditions for a longer time.

The pH showed no effect on the *C. jamacaru* seed germination and seedling development. However, the interaction of pH and osmotic potential showed significant effect in some variables such as ShL and SL.

Conclusions

Cereus jamacaru species showed susceptibility to water deficit at seed germination and seedling development stages.

The pH interaction with osmotic potential affected *C. jamacaru* seedling development. The increase in pH was favorable for seedling development, but not for seed germination.

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