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Environmental stress, future climate, and germination of *Myracrodruon urundeuva* seeds[1]

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ABSTRACT – *Myracrodruon urundeuva*, a native species from the Brazilian *Caatinga*, is widely distributed across its endemic region, where it also plays an essential socioeconomic role. The objective of this study was to evaluate the influence of environmental stress on the germination of *M. urundeuva* seeds harvested in different years (2010 to 2013). Seeds were germinated at constant temperatures between 10 to 40 °C, osmotic potentials from 0 to -0.8 MPa (in polyethylene glycol 6000 solutions), and from 0 to -0.5 MPa (in NaCl solutions). The experiment was conducted according to a completely randomized design, with three replicates of 50 seeds, in a factorial scheme (harvest year x stress intensity) for each environmental stress. Germination data were then analysed using thermal, hydro and halo time models, and future germination responses projected according to climate change scenarios. The germination thermal thresholds ranged from 7.4 to 53.3 °C. The germination base osmotic threshold (using polyethylene glycol) was -0.6 MPa and the base osmotic threshold in NaCl was -0.43MPa. Seeds from different harvest years showed distinct tolerance to environmental stresses. The thermal, hydro and halo-time models were efficient to describe the germinative response of seeds, and the climate models allowed to identify the germination responses of *M. urundeuva* in future climate. According to the models for future climate (RCP 8.5), the reduction of rainfall by 2100 will directly affect seed germination and seedling recruitment of *M. urundeuva.*

Index terms: *Caatinga*, forest seeds, osmotic potential, temperature.

Estresses ambientais, clima futuro e germinação de sementes de *Myracrodruon urundeuva*

RESUMO – *Myracrodruon urundeuva*, espécie nativa da Caatinga e de ampla distribuição geográfica, apresenta relevante valor socioeconômico. Objetivou-se avaliar a influência de estresses ambientais sobre a germinação de lotes de diferentes safras de *M. urundeuva*. Foram testadas as temperaturas constantes de 10 a 40 °C e potenciais osmóticos de 0 a -0,8 MPa (usando-se polietileno glicol 6000) e de 0 a -0,5 MPa (usando-se soluções de NaCl). O delineamento experimental foi inteiramente casualizado com três repetições de 50 sementes em esquema fatorial (safras x intensidade do estresse) para cada estresse abiótico. Os dados de germinação foram então analisados utilizando modelos de tempo térmico, hídrico, hálico (salino), projetando respostas de germinação em cenários climáticos futuros. Os limites térmicos para a germinação das sementes variaram entre 7,4 e 53,3 °C. O limite osmótico base para germinação de sementes em polietileno glicol foi de -0,6 MPa e em NaCl foi de -0,43 MPa. Segundo modelos de cenários futuros de mudanças climáticas, a redução de semanas com precipitação mínima afetará diretamente a germinação de sementes e o recrutamento de plântulas de *M. urundeuva.* Assim, conclui-se que sementes de *M. urundeuva* foram tolerantes aos estresses abióticos. Os modelos de tempo térmico, hídrico e hálico foram eficientes para descrever a resposta foram eficientes para descrever a resposta germinativa de sementes, e os modelos climáticos permitiram identificar as respostas germinativas de *M. urundeuva* em cenários futuros de mudanças climáticas. De acordo com os modelos para clima futuro (RCP 8.5), a redução da precipitação até 2100 afetará diretamente a germinação de sementes e recrutamento de plântulas de *M. urundeuva.*

Termos para indexação: Caatinga, sementes florestais, potencial osmótico, temperatura.

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Introduction

Climate projections published in the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) indicate increasing emission of greenhouse gases (GHG) as the primary cause for temperature changes. As an outcome, future climate scenarios include a increase of the average global temperature and a decrease in the precipitation levels (IPCC, 2014), which can alter the salinity of the soil (Knowles and Cayan, 2002; Gondim et al., 2010). In some areas more susceptible to the risks imposed by climate alterations, such as the *Caatinga* biome in Brazil's Northestern region, the aridity may be intensified, which might even lead to desertification (Marengo et al., 2016) and increased soil salinity.

Climate change may have important consequences to all stages of plant development, from seed germination to growth and establishment of species (Maraghni et al., 2010). Germination is an ecophysiological process fundamental to plant diversity (Bewley et al., 2013), which depends on the environmental conditions to which seeds are subjected to. Thus, the capacity of seeds for germinating in a broad variety of conditions assures the survival and regeneration of species (Vivian et al., 2008).

The knowledge of the environmental conditions which interfere in production and germination of seeds is fundamental. Temperature influences germination by affecting the speed of water imbibition, and also on biochemical and enzymatic reactions ruling the entire process (Flores et al., 2014). Changes in the environmental temperature may also affect the permeability of membranes (Maraghni et al., 2010). Thus, germination only occurs within certain species-specific temperature limits (Bewley et al., 2013).

The germinative process depends on the availability of water and its movement through the tissues surrounding the seed. In this sense, the excess of salt in the substrate affects the availability of water to seeds, by inhibiting or slowing down its absorption (Chaves et al., 2009). Besides, the buildup of Na^+ and Cl^- ions causes ruptures in seed tegument layers and has a toxic effect, which might lead to the death of seeds (Freitas et al., 2013). In the field, such conditions are naturally induced by low precipitation levels, soil salinization, and high temperatures, phenomena that can compromise the germination, initial development, and recruitment of plants, even of those that are well-adapted to hot-dry climates.

Myracrodruon urundeuva Allemão (Anacardiaceae), known as *aroeira-do-sertão*, is a species widely spread throughout the Brazilian territory, which also plays an essential socioeconomic role. Its bark is rich in phenolic compounds with cicatrizing and anti-inflammatory properties (Carlini et al., 2010). Also, its wood has considerable mechanical resistance and does not putrefy easily, thus being largely used in construction and furniture. However, since its use is mostly connected to uncontrolled exploitation, its survival is critically under threat (CNCFlora, 2012).

Some studies have been conducted to better understand the germination behavior of *M. urundeuva* exposed to different environmental factors (Virgens et al., 2012; Guedes et al., 2011). However, there are no studies that predict germination in future climate scenarios, simultaneously considering seed lots obtained from different harvests, of varying physiological quality, and the response to alterations in temperature and water availability. This information is essential to appraise the adaptation capacity of this species (Seal et al., 2017).

The primary objective of this work was to evaluate the influence of environmental conditions on the germination of different lots of *M. urundeuva*. Thus, different temperatures (simulating thermal stress) and osmotic potentials, obtained with polyethylene glycol – PEG (simulating drought stress) and NaCl (simulating salt stress), were assessed. The hypothesis tested was that seeds with different physiological qualities respond differently to these environmental stresses. Besides that, thermal and osmotic limits were determined, based on thermal time, hydrotime and halotime models (Bradford, 2002; Seal et al., 2018). The goal was to evaluate the efficiency of those models and describe the germinative behavior of *M. urundeuva* seeds in adverse conditions. Lastly, current climate data and projections were used to predict how these seeds might germinate in future climate scenarios.

Material and Methods

Harvest and seed processing

Diaspores of *M. urundeuva* were collected directly from mother-plants in a partially human-degraded *Caatinga* area at the municipality of *Lagoa Grande*, Brazilian state of *Pernambuco* (8°34'13.1"S, 40°11'02.2"W). The harvests occurred between August and September of 2010, 2011, 2012, and 2013, from the same population. Seed processing included a manual pre-cleaning, in which diaspores had the wings detached, and branches were removed. Then, a seed blower was used to clean off any remaining dirt (Matias et al., 2014). The diaspores were packed in cloth bags (permeable) and placed inside a cold chamber (T=10 °C, RH=45%), where they remained until January 2014. The water content of *M. urundeuva* seed lots at the beginning of the germination experiments was of 9.47; 9.36; 10.02; and 10.04% for the lots harvested in 2010, 2011, 2012, and 2013, respectively (Brasil, 2009).

Previous and future climate data

Monthly data on air temperature and precipitation of the different harvests were gathered at the Automated Agro-meteorological Station of *Bebedouro*, at *Embrapa Semiárido*, based in *Petrolina*, state of Pernambuco (09°09' S, 40°22'W) within a distance of 64.5 km from the mother-trees (Figure 1). Historical average data (from 1970 to 2017), concerning the Meteorological Field Station of *Caatinga* and obtained by the Agro-meteorology Laboratory at *Embrapa Semiárido* (09°13'S, 40°29'W), were also used. The RCP 8.5 scenario was taken as a forecast, giving an average temperature rise of 3.5 ºC (IPCC, 2014) and a precipitation reduction of 40% (PBMC, 2013) until 2100.

Germination of seeds at different temperatures and osmotic potentials

Prior to the germination experiments, the diaspores were submerged in neutral detergent for five minutes. Then, the seeds were extracted by manually removing the exocarp and mesocarp of the diaspores under running water, with the aid of a steel sieve. Next, the seeds were superficially disinfested by immersion in a commercial chlorine solution (bleach) for three minutes, and then they were treated with the fungicide Captan® (3 mL. L^{-1}) for another three minutes.

The experimental design was completely randomized, and three replicates of 50 seeds were used in every trial assessing the influence of environmental conditions on the germination of *M. urundeuva*. To evaluate the effect of temperature, a 7x4 factorial scheme was employed, which corresponded to seven constant temperatures (10, 15, 20, 25, 30, 35, and 40 °C) and the seed lots from four harvest-years (2010, 2011, 2012, and 2013). The effect of drought was analyzed using an 6x4 factorial scheme, with six osmotic potentials (0, -0,2, -0,4, -0,6, -0,7 e -0,8 MPa) using aqueous solutions of polyethylene glycol- PEG 6000 and the four seed lots. The effect of salinity was analyzed by using an 8x4 factorial scheme, with eight osmotic potentials obtained from NaCl solutions (0, -0.072, -0.144, -0.216, -0.288, -0.360, -0.432, and -0.504 MPa) and the four seed lots.

Myracrodruon urundeuva seeds from different lots were sown in acrylic boxes (dimensioned 11 x 11 x 3.5 cm), containing two blotting paper sheets as substrate. They had been moistened with distilled water or one of the solutions (NaCl or PEG6000) mentioned above, in a proportion of 2.5 times the dry paper weight (Brasil, 2009). Next, the seeds were incubated for 14 days, in a 12 h photoperiod, at constant temperatures of 10 to 40 ºC (temperature effect) or 25 ºC (osmotic or salinity effect). Germination was, considered as 1 mm of primary root visible, and was evaluated 12 h after setting the experiment,

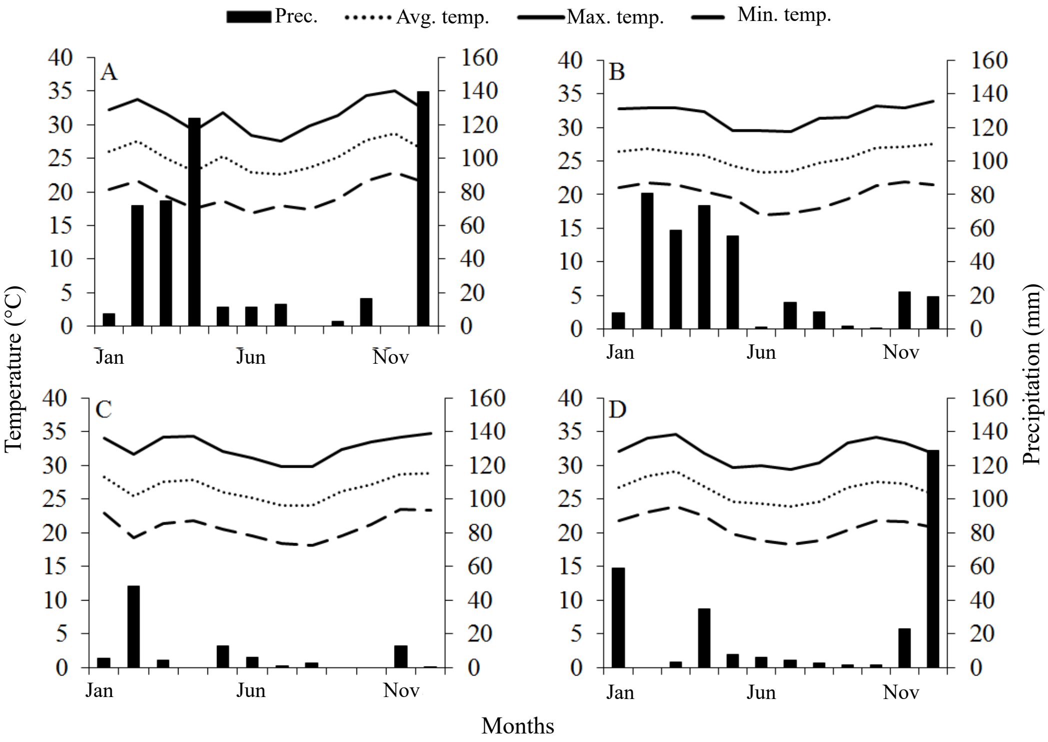


Figure 1. Total precipitation (prec) and average, maximum and minimum air (Avg. temp., Max. temp. and Min. temp., respectively) in 2010 (A), 2011 (B), 2012 (C), and 2013 (D), in the city of *Petrolina* – PE.

and then at every hour until its stabilization.

The physiological quality of the seeds was appraised by the final germination percentage (G%) after 14 days (Brasil, 2013) and by the germination speed index (GSI) (Maguire, 1962). The data were subject to analysis of variance with the software *Assistat*, and then submitted to regression analysis (Silva and Azevedo, 2016).

Obtaining thermal time and hydrotime of seeds

The cumulative germination was plotted as a function of time for each temperature, and then fitted to sigmoidal Boltzmann curves. The germination rate (GR) was calculated as a reciprocal function of the time necessary to reach 50% germination ($1/t_{50}$) (Covell et al., 1986). By knowing the GR values associated with each temperature, linear regression analysis was performed. They allowed the calculation of the interception on the x-axis, at the sub- and supra-optimum temperature ranges, generating estimates for the base temperature (T_b) and ceiling temperature (T_c). Below and above these values, respectively, the GR is equal to zero (Covell et al., 1986; Ellis et al., 1986). The interception between the two regression lines at the sub- and supra-temperatures was used to estimate the optimum temperature (T_o) (Hardegree, 2006).

The thermal time of the population that germinated at sub-optimum temperatures (θ_{Tsub}) and that of the population that germinated at supra-optimum (θ_{Tsupra}) temperatures were estimated using the following equations:

$$\theta_{Tsub} = (T - T_b)\, t \qquad \text{(equation 1)}$$

$$\theta_{Tsupra} = (T_c - T)\, t \qquad \text{(equation 2)}$$

Where T it the germination temperature; T_b is the base temperature; T_c is the ceiling temperature; and t is the time since the imbibition started (Covell et al., 1986).

The germination percentages corresponding to each osmotic potential (ψ) studied were graphically represented as a function of time. Then, a regression analysis was conducted, as above mentioned, to determine the interception on the x-axis, producing estimates of the base osmotic potential (ψ_b), below which the GR is null (Gummerson, 1986). Germination responses concerning the osmotic potential were also described according to the hydrotime (θ_H) or halotime (θ_{HNaCl}) scale, which was calculated for each osmotic and salt treatment as follows (Gummerson, 1986; Bradford, 2002; Seal et al., 2018):

$$\theta_H \text{ or } \theta_{HNaCl} = (\psi - \psi_b)\, t \qquad \text{(equation 3)}$$

Where ψ is the osmotic potential; ψ_b is the osmotic base potential; and t is the time since imbibition started.

Germination prediction for current and future climate

Previous climate data and the future RCP 8.5 scenario (IPCC, 2014) were used to calculate the environmental thermal sum and to predict seed germination, by using the parameters T_b, T_c, T_o, θ_T, ψ_b, and θ_H.

The heat sum was calculated weekly (as long as the precipitation of the week in analysis had reached a minimum level of 20 mm (Santos et al., 2011); according to the following equation:

$$\text{Heat sum} = (T_m - T_b)/t \ \ (^{o}\text{Cd}^{-1}) \qquad \text{(equation 4)}$$

Where T_m is the average week temperature; T_b is the base temperature, below which germination does not occur; and t is the number of days until reaching the thermal time for germination (θ_T).

Results and Discussion

Effects of the environmental stress on germination

All seed lots of *M. urundeuva* (2010, 2011, 2012, and 2013) showed germination rates above 70%, by the end of 14 days (336 h) of evaluations at temperatures between 20 to 35 ºC (Figures 2, and 3A). In addition, the beginning of germination was earlier at temperatures from 25 ºC to 35 ºC. At this range, 24 h (lots 2010, 2011, and 2013) to 28 h (lot 2012) of imbibition were necessary for germination (Figure 2), and the maximum GSI value was obtained (Figure 3B). Seeds of the 2013 lot were more tolerant to high temperature, with a 40% germination rate, even when subjected to 40 ºC. Such an outcome contrasts with the other lots, whose germination remained below 10% (Figures 2, and 3A). On the other hand, by the end of the evaluation period, the lots harvested in 2010 and 2013 showed germination values of 10 and 11%, respectively, when incubated at 10 ºC (Figures 2, 3A).

The germination rate (GR) has commonly been used to obtain the germination limits of seeds of several species (Covell et al., 1986; Bradford, 2002; Arana et al., 2016; Seal et al., 2017, 2018; Castillo-Lorenzo et al, 2019) due to its linear relation with temperature (Covell et al., 1986). On account of that, the temperature limits, as well as the sub- and supra-optimum thermal times (Figure 4) could be calculated for germination of *M. urundeuva* seeds. All seed lots germinated at a wide thermal range, with base temperature (T_b) below 10 ºC, except for the 2011 lot (10.3 °C). The values of ceiling temperature (T_c) of all seed lots studied were above 40 ºC (Figure 4). About 5% germination of the 2010 seed ocurred at 10 and 40 ºC (Figure 3A), showing tolerance to a broader temperature range (7.4-50.7 ºC) than the other lots (Figure 4), even after four years of storage.

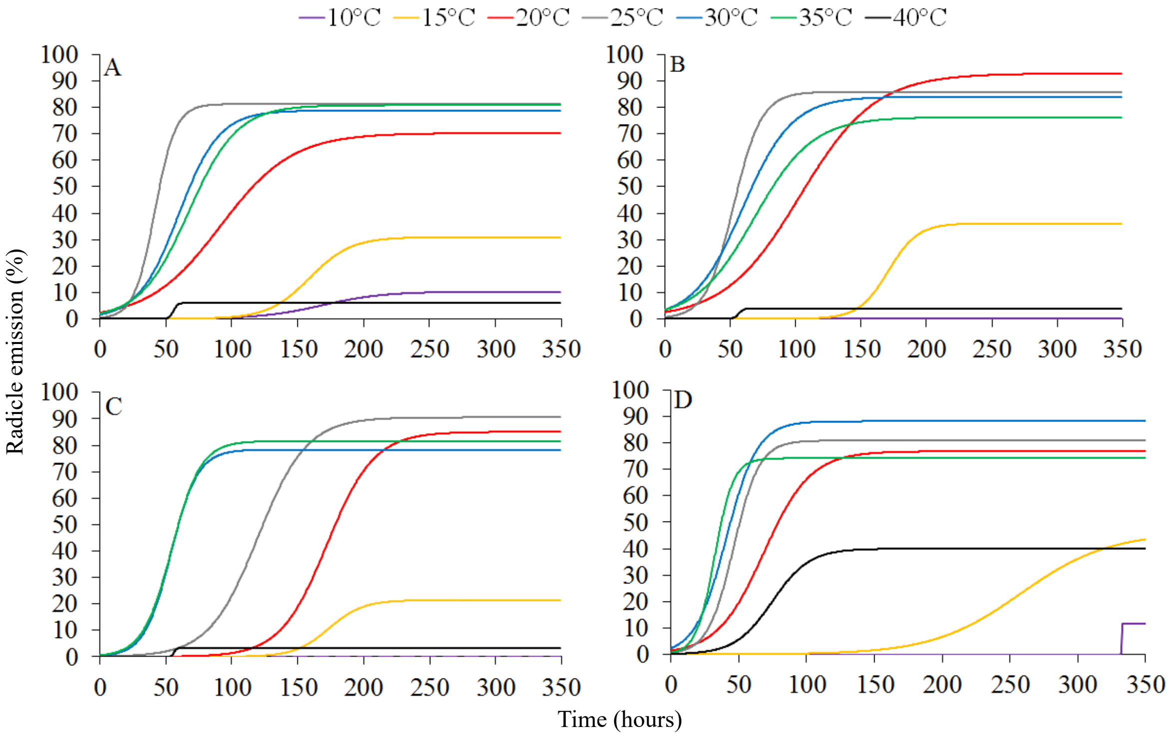
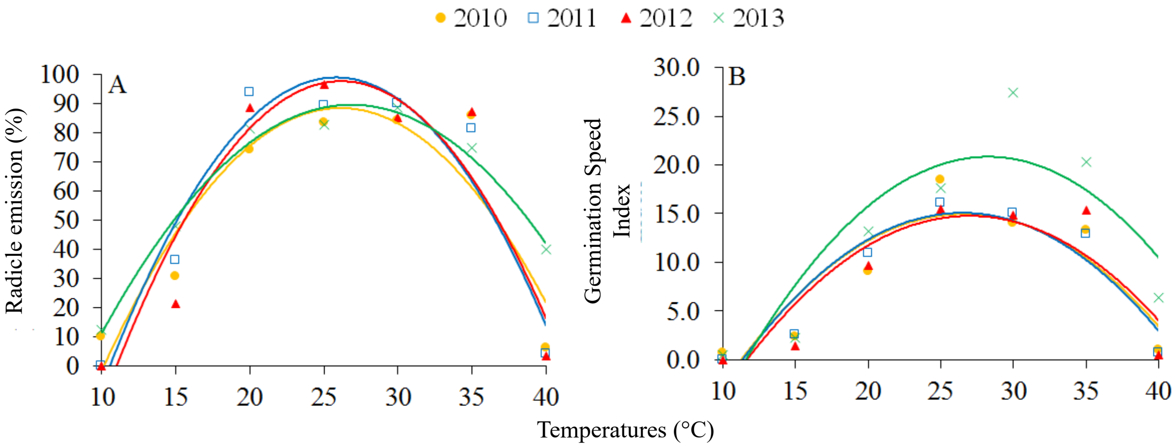


Figure 2. Germination curves (radicle emission percentage) of *Myracrodruon urundeuva* harvested in 2010 (A), 2011 (B), 2012 (C), and 2013 (D), after non-linear fitting, according to the Boltzmann sigmoidal model, as a function of different temperatures.



(2010)$y = 29.86x^2 - 306.60x + 1168.26$; $R^2 = 0.99$
(2011)$y = 33.65x^2 - 338.96x + 1248.71$; $R^2 = 0.99$
(2012)$y = 50.32x^2 - 526.97x + 2030.33$; $R^2 = 0.99$
(2013)$y = 6.67x^2 - 57.13x + 170.10$; $R^2 = 0.98$

(2010)$y = 0.81x^2 - 11.36x + 52.21$; $R^2 = 0.93$
(2011)$y = 0.16x^2 - 1.69x + 3.17$; $R^2 = 0.97$
(2012)$y = 5.52x^2 - 59.55x + 235.81$; $R^2 = 0.99$
(2013)$y = 0.36x^2 - 5.69x + 26.67$; $R^2 = 0.96$

Figure 3. Germination (A) and average speed index (B) of *Myracrodruon urundeuva* seeds from different lots subjected to different temperatures.

Fresh seeds of *M. urundeuva* collected in 2007 from the same population, exhibited maximum germination at 25 ºC, and no germination at 40 ºC (Virgens et al., 2012), while the seeds from all lots collected between 2010 and 2013 showed some germination at 40 ºC, and optimum temperature (T_o) varied between 26.6 to 34.7 ºC (Figure 3).

These results indicate that lots from different harvests can respond differently to environmental conditions during the germination stage.

The adequate temperatures to evaluate *M. urundeuva* seeds are known to be 25 ºC or 20-30 ºC, based on seeds harvested from regions with milder temperatures than those studied in

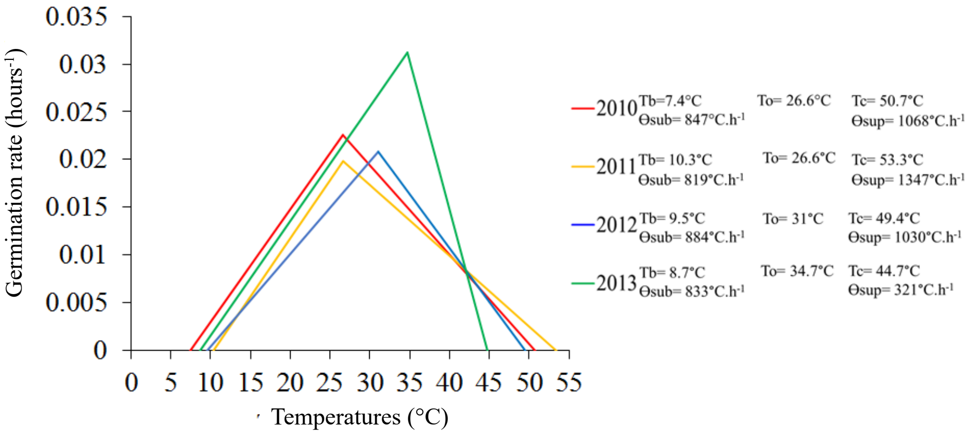


Figure 4. Germination rate (GR), thermal limits and requirements of *Myracrodruon urundeuva* seeds harvested in 2010, 2011, 2012, and 2013, and subjected to different temperatures. T_b and T_c correspond to base and ceiling temperatures for germination, respectively (the point on which the regression curves intercept the x-axis); T_o is the optimum temperature; θ_{sub} and θ_{supra} correspond respectively to the thermal time of the sub- and supra-optimum temperature ranges, obtained by the reciprocal function of the regression curve angle.

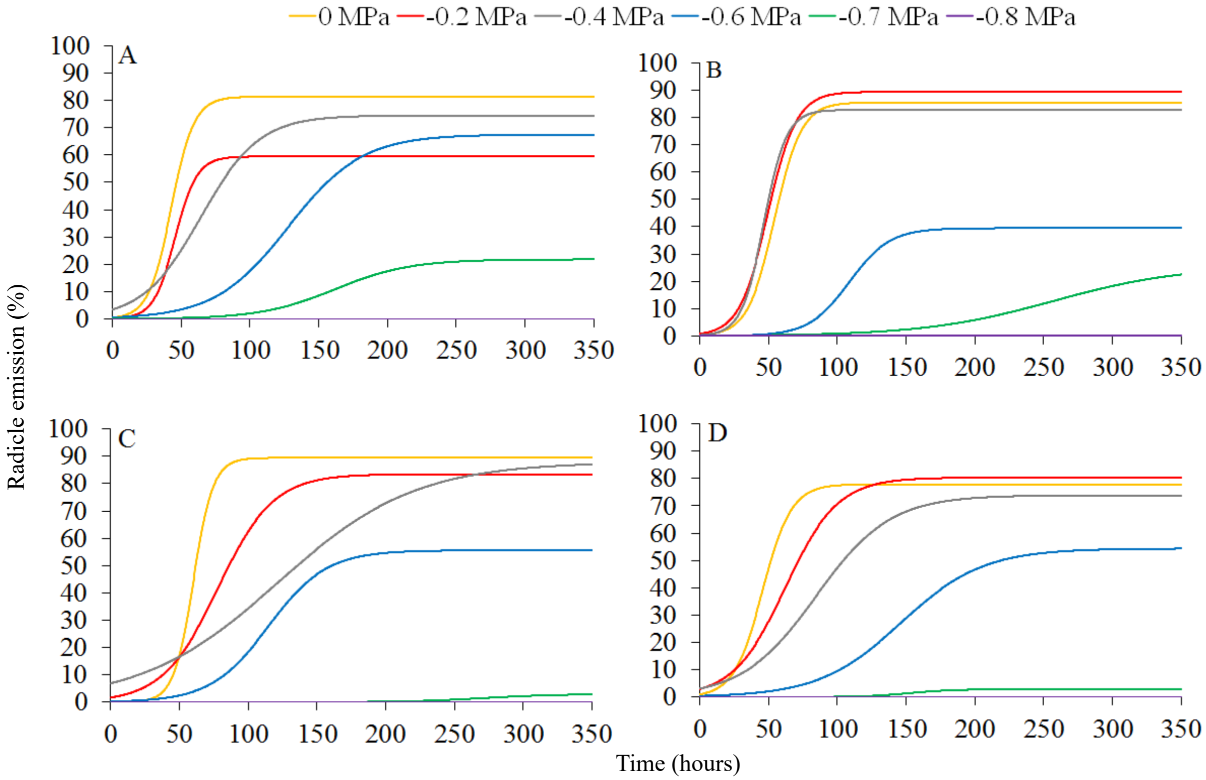
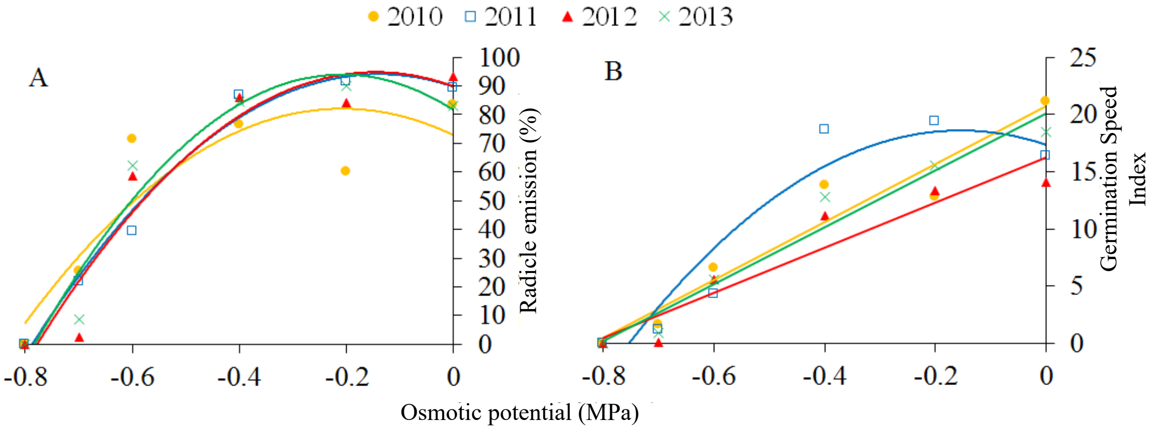


Figure 5. Cumulative germination of *Myracrodruon urundeuva* seeds harvested in 2010 (A), 2011 (B), 2012 (C), and 2013 (D), and fitted according to the Boltzmann sigmoidal model, as a function of different osmotic potentials produced from polyethylene glycol 6000.

this work (Brasil, 2013). Such a difference indicates that the surrounding conditions where the mother-plants are found can affect seeds responses to the environment (Bewley et al., 2013).

Germination in all *M. urundeuva* seed lots was gradually reduced as the osmotic potential increased (Figures 5, 6). Seeds of the 2012 lot started to germinate after 28 h imbibition; while in those of 2011, 2012, and 2013 lots, the process only began after 40 h of imbibition (Figure 5). By the end of the evaluation period, the maximum germination was verified in all lots when seeds were submitted to up to -0.4 MPa. At -0.6 MPa, seeds of 2010 lot still germinated above 60% (Figure 6), but at -0.8 MPa, seeds of all lots failed to germinate. Other *Caatinga*-native species, such as *Zizyphus joazeiro* (Lima and Torres, 2009), *Mimosa ophthalmocentra* (Nogueira et al., 2017), *Cenostigma pyramidale* (sin. *Poincianella pyramidalis)*, and *Anadenanthera colubrina* (Santos et al., 2016) showed the same behavior regarding water restriction.

The inclination of the regression curves for germination rate showed that the 2010 lot was the most vigorous and tolerant to water restrictions, reaching a base water potential (ψ_b) of -1.1 MPa (Figure 7). Seed vigour can be accounted for such a tolerance to negative osmotic potentials, since



$(2010) y = 26.68x^2 - 49.94x + 83.64; R^2 = 0.97$
$(2011) y = 51.25x^2 - 50.31x + 89.33; R^2 = 0.99$
$(2012) y = 27.73x^2 - 41.33x + 93.76; R^2 = 0.96$
$(2013) y = 14.08x^2 - 14.69x + 83.50; R^2 = 0.95$

$(2010) y = -12.86x + 21.09; R^2 = 0.99$
$(2011) y = 16.02x^2 - 14.28x + 16.32; R^2 = 0.97$
$(2012) y = 1.44x + 13.83; R^2 = 0.97$
$(2013) y = 0.18x + 18.24; R^2 = 0.98$

Figure 6. Germination (A) and germination speed index (B) of *Myracrodruon urundeuva* seeds subjected to water stress by different PEG-6000 osmotic potentials.

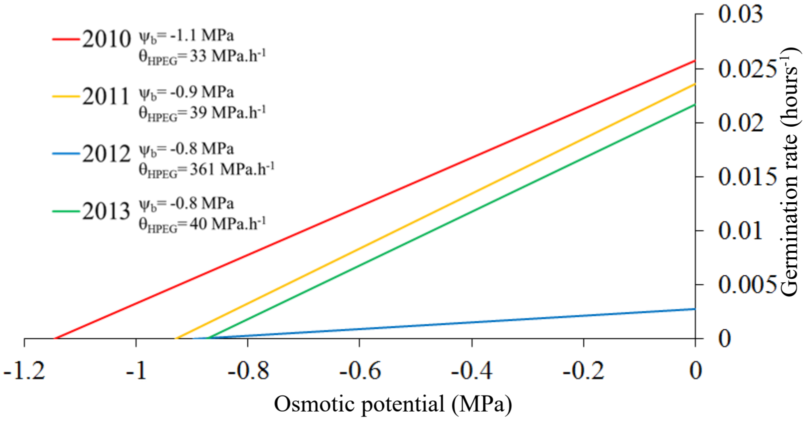


Figure 7. Germination rate, osmotic limits and requirements of *Myracrodruon urundeuva* seeds harvested in different years and subjected to different osmotic potentials produced from PEG-6000 solutions. ψ_b corresponds to the osmotic base potential for germination (the point on which the regression curves intercept the x-axis); θ_{HPEG} corresponds to the hydrotime, obtained by the reciprocal function of the regression curve angle.

2010 had higher rainfall volume than other harvests, during sprouting (October to June) and flowering of male and female individuals (June to September and July to August, respectively) (Kiill et al., 2010) producing bigger and more vigourous seeds. Studies on the phenophases of *M. urundeuva* in a semi-arid environment verified that fruitification occurs from August to November (Nunes et al., 2008). Variations in the precipitation levels were observed between different seed harvests (Figure 1), which affected the levels of activity and intensity of each phenophase. Water availability patterns during the phenophases, mostly during flowering and fruitification, is probably the main factor ruling plant reproduction in tropical regions, especially in dry tropical forests (Griz and Machado, 2001).

Seeds of the 2010, 2011, and 2013 harvests showed a germination rate relatively higher than those of the 2012 lot when there was no water restriction involved. Also, even though seeds harvested from 2011-2013 exhibited similar ψ_b (-0.8 to -0.9 MPa), the hydrotime (θ_{HPEG}) proved that 2012 seeds required more time to conclude their germination in water restriction. This response is in agreement with the low vigor of the lot, which, in its turn, might be linked to an unusually severe drought, with 65% less rainfall than the historical average (Souza et al., 2017; Salimon and Anderson, 2018), mainly during the flowering season (Figure 1).

As for the effect of salinity on *M. urundeuva* seeds, in general, treatments with osmotic potential above -0.216 MPa commenced germination more quickly when compared to the other osmotic potentials tested (Figure 8). The maximum germination, by the end of 14 days (336 h) evaluation, was verified in seeds of all lots at osmotic potential above -0.072 MPa. Below -0.144 MPa, as the NaCl concentration increased, the germination percentage reduced significantly and gradually until its total inhibition at -0.504 MPa (Figure 9A). The germination speed index (GSI) of seeds of all lots showed higher values when in distilled water, rather than in the other treatments (Figure 9B). This is likely to be the consequence of both ionic toxicity and osmotic stress that can delay germination by affecting physiological and metabolic phenomena in the embryonic tissues (Voigt et al., 2009).

The models generated from *M. urundeuva* germination rates at different NaCl concentrations indicated that the 2010, 2011, and 2012 lots were more tolerant to salinity than the 2013 lot (Figure 10). The base osmotic potential (ψ_b) presented values between -0.5 to -0.7 MPa for the saline solutions assessed (Figure 10). Also, the reduction in osmotic

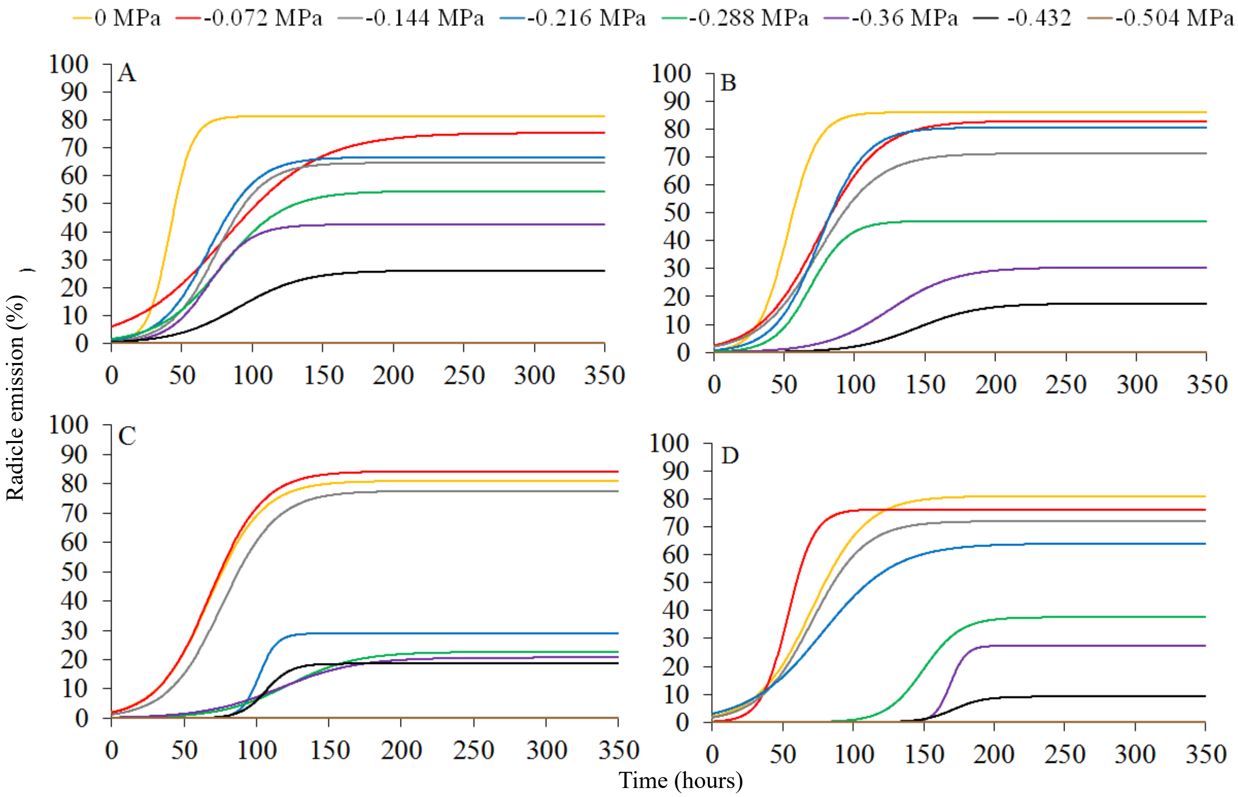
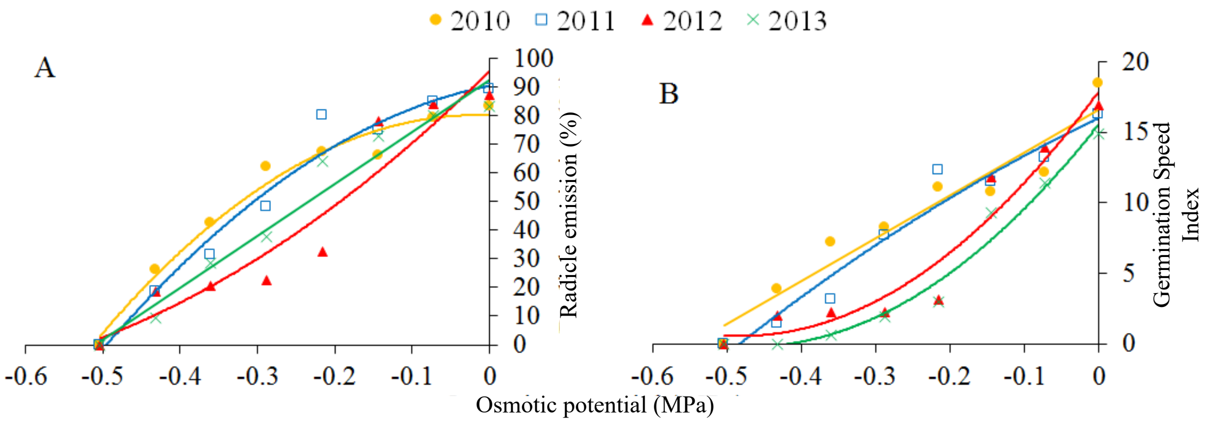


Figure 8. Cumulative germination of *Myracrodruon urundeuva* seeds harvested in 2010 (A), 2011 (B), 2012 (C), and 2013 (D), and fitted according to the Boltzmann sigmoidal model, as a function of different osmotic potentials obtained with NaCl.

potential induced by NaCl had a more detrimental effect on the germination rate than that produced by PEG6000 (Figures 8 and 10). This fact might be the outcome of the Na^+ buildup, which alters the ionic equilibrium and the availability of mineral nutrients, thus decreasing the cellular division and embryonic development (Moss and Hoffman, 1977). The values of halo-time (θ_{HNaCl}) were also different among the studied lots, and the 2012 lot required more time to complete germination in saline conditions (Figure 10).

The ability to germinate under extreme conditions allows the geographical and temporal distribution of a species, therefore optimizing its survival (Oliveira et al., 2017). So, the success of a species in heterogeneous environments relies on its plasticity (Lima et al., 2010). This capacity was evidenced in the present study by evaluating lots of *M. urundeuva* at different environmental conditions. The responses displayed by this species are associated with its diverse strategies to adapt to its surroundings (Guedes et al., 2013).



(2010) $y = 0.48x^2 - 4.35x + 83.69; R^2 = 0.98$
(2011) $y = 7.45x^2 - 13.93x + 89.93; R^2 = 0.98$
(2012) $y = -8.25x^2 + 15.72x + 85.14; R^2 = 0.97$
(2013) $y = -1.28x^2 + 2.07x + 82.27; R^2 = 0.99$

(2010) $y = -4.5x + 18.33; R^2 = 0.99$
(2011) $y = 1.90x^2 - 4.56x + 16.43; R^2 = 0.98$
(2012) $y = -1.14x^2 + 0.94x + 16.70; R^2 = 0.97$
(2013) $y = 1.07x^2 - 3.27x + 18.53; R^2 = 0.99$

Figure 9. Germination (A) and germination speed index (B) of *Myracrodruon urundeuva* seeds subjected to salt stress at different NaCl osmotic potentials.

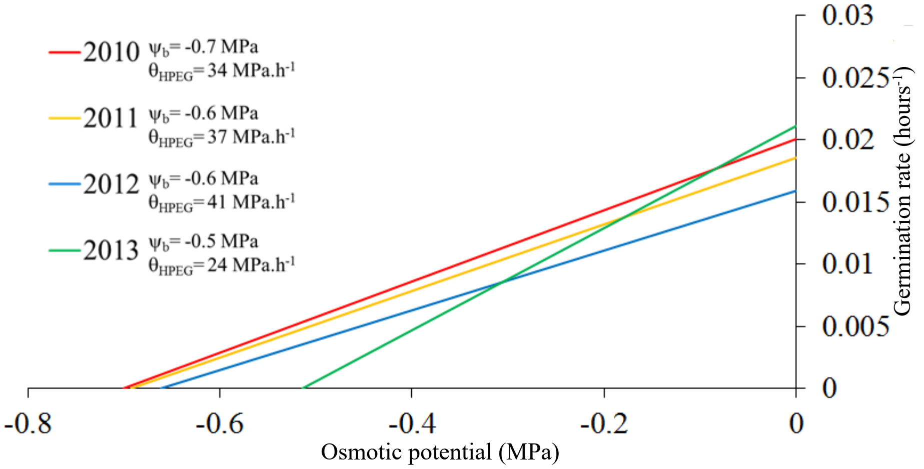


Figure 10. Germination rate, osmotic limits and requirements of *Myracrodruon urundeuva* seeds harvested in different years, and subjected to different osmotic potentials produced with NaCl solutions. ψ_b corresponds to the osmotic base potential for germination (the point on which the regression curves intercept the x-axis); θ_{HNaCl} corresponds to the hydrotime, obtained by the reciprocal function of the regression curve angle.

Predictions for germination in future climate conditions

The heat sum for seed germination was estimated based on the climate data and thermal threshold parameters (equation 4). However, only weeks in which the precipitation surpassed a minimum of 20 mm were taken into account, because this is the ideal rainfall volume to maintain the *Caatinga* soil moisture at adequate levels for germination for one week (Santos et al., 2011). For the current climate, the heat sum for germinating seeds of older lots (2010-2012) remained between 35 to 40 °Cd^{-1}, and for seeds of younger lots, it was 25 °Cd^{-1}. For the predictions of future climate conditions, even with more thermal energy existing in the environment, the estimated heat sum was similar to that of the current climate (Figure 11). Also, the average environmental temperature will never surpass the ceiling temperature (T_c) for this species germination (Figure 4), indicating that the future warming will not restrict the germination of these seeds.

On the other hand, a 40% reduction in the rainfall volume, as predicted by the RCP-8.5 scenario, will result a decrease in the number of weeks with enough available water for seed germination and initial development of *M. urundeuva*, thus restraining the recruitment of seedlings. This trend can already be verified in the drought years of 2011 to 2017 (Marengo et al., 2016), as well as in the rainy season between 2016 and 2017, when the precipitation levels remained below 20 mm per week. In both cases, the emergence of seedlings of *M. urundeuva* from seed banks was compromised (Silva et al., 2017).

Conclusions

Myracrodruon urundeuva seeds are tolerant to a broad range of temperatures and osmotic potentials. Nevertheless, such a tolerance depends on the physiological quality of the lots.

Salinity had an effect more detrimental to *M. urundeuva* seed germination than water restriction.

Climate models allowed identifying *M. urundeuva* germinative responses in future climate scenarios, which indicate that the lack of rainfall will affect seed germination and initial development, regardless of temperature increase.

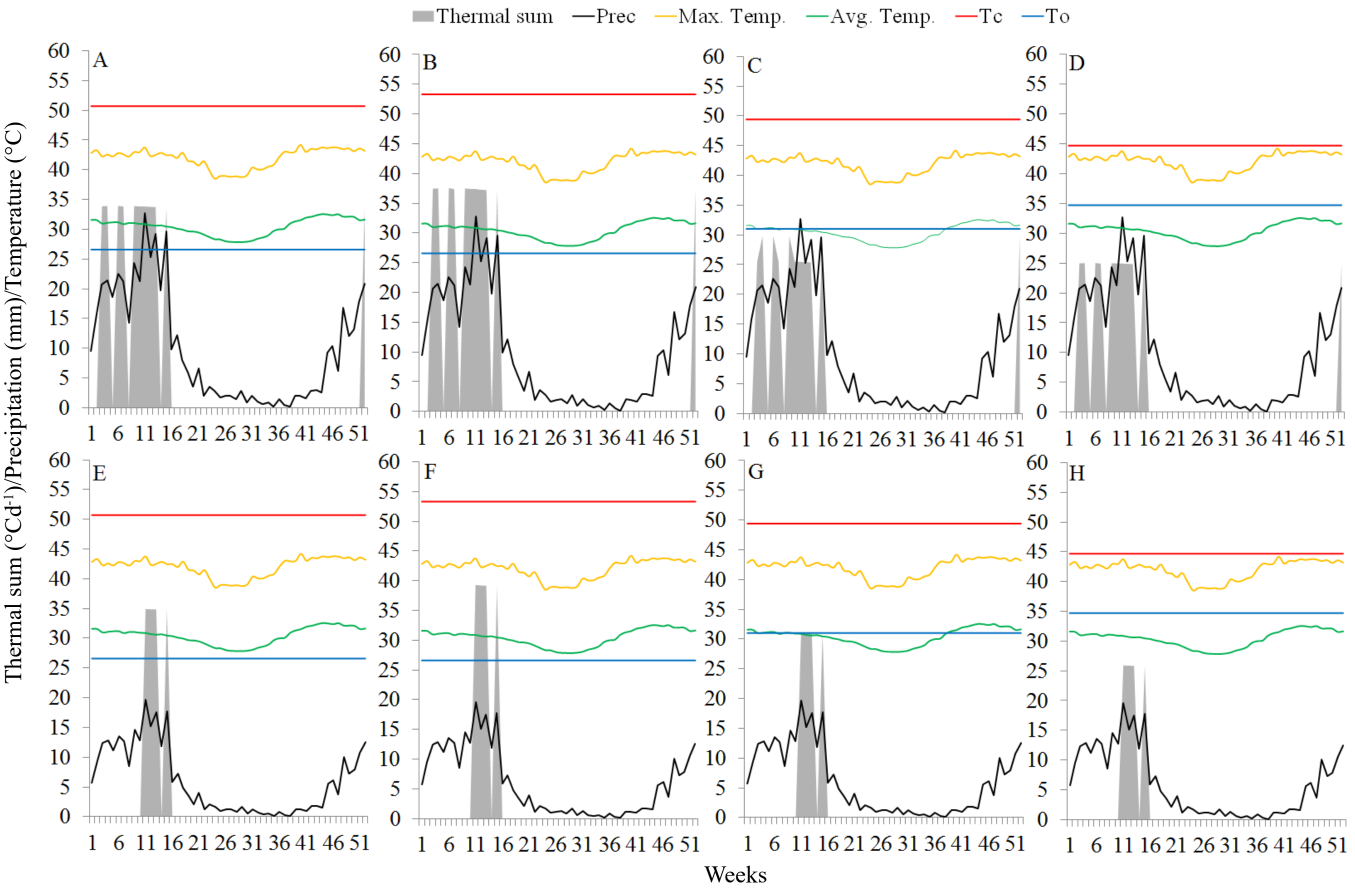


Figure 11. Thermal sum required for the germination events of *Myracrodruon urundeuva* seeds of the 2010 (A, E), 2011 (B, F), 2012 (C, G), and 2013 (D, H) lots, considering the current climate scenario (A, B, C, and D) and the RCP 8.5 climate prognosis (E, F, G, and H), stated by the Intergovernmental Panel on Climate Change – IPCC/AR5 (IPCC, 2014).

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