Climate and the Myracrodruon urundeuva Allemão seed production

Gilmara Moreira de Oliveira¹, Francislene Angelotti², ¹Emanuel José Nascimento Marques, ³Fabrício Francisco Santos da Silva, ⁴Claudineia Regina Pelacani, ²Barbara França Dantas

¹Pós-doutorado (BFP-FACEPE), e-mail: gilmara_5@hotmail.com (autor correspondente) ²Embrapa Semiárido. ³Pesquisador do Núcleo de Ecologia e Monitoramento Ambiental da UNIVASF (NEMA/UNIVASF). ⁴Professora do Departamento de Ciências Biológicas (UEFS)

Artigo recebido em 30/03/2020 e aceito em 30/11/2020

ABSTRACT

The seed physiological quality is related with climate variation during development. Thus, the aim of this study was to determine the relation among climatic factors and germination of Myracrodruon urundeuva seeds in different growing seasons and to predict the germination according to the climatic scenarios. Seeds from 14 crop seasons (2005 to 2018) and climatic data from the ‘Bebedouro’ weather station (Embrapa Semiarid) were used to determine the influence of climatic conditions on the vegetative, female and male flowers and the fruiting of Myracrodruon urundeuva. The simple linear correlation and the multiple linear regression model were applied to determine the influence of climatic elements on the production of Myracrodruon urundeuva seeds. The multivariate calibration model was developed using the previous selection of variables by the algorithm of successive projections. From the mathematical model, the germination of Myracrodruon urundeuva seeds was predicted according to climate change, as provided by the IPCC. Seed germination showed a significant difference between harvests. Through the correlation it was observed that the temperature correlated negatively with all phenological phases of Myracrodruon urundeuva. The quality of Myracrodruon urundeuva seeds is related to the maximum, average and minimum temperature, average and minimum humidity, and precipitation. These climatic variables during the different phenological phases of Myracrodruon urundeuva affect the physiological quality of the seeds, and, in climate change scenarios, there will be a reduction in the seed production of this species.

Keywords: araçoeira-do-sertão, climate changes, germination.

O clima e a produção de sementes de Myracrodruon urundeuva Allemão

RESUMO

A qualidade fisiológica das sementes está relacionada às variações climáticas durante o seu desenvolvimento. Assim, o objetivo deste trabalho foi determinar a relação entre os elementos climáticos e a germinação de diferentes safras de sementes de Myracrodruon urundeuva, bem como prever a germinação frente aos cenários climáticos. Foram utilizadas sementes de 14 safras (2005 a 2018) e os dados climáticos da estação meteorológica de Bebedouro, pertencente a Embrapa Semiarido, para determinar a influência das condições climáticas nas fases vegetativa, flores femininas e masculinas e da frutificação de Myracrodruon urundeuva. A correlação linear simples e o modelo de regressão linear múltipla foram aplicados para determinar a influência dos elementos climáticos na produção de sementes de Myracrodruon urundeuva. O modelo de calibração multivariado foi desenvolvido empregando a seleção prévia de variáveis pelo algoritmo das projeções sucessivas. A partir do modelo matemático realizou-se a previsão da germinação de sementes de Myracrodruon urundeuva frente às mudanças climáticas, previstas pelo IPCC. A germinação das sementes apresentou diferença significativa entre as safras. Por meio da correlação observou-se que a temperatura correlacionou negativamente com todas as fases fenológicas da Myracrodruon urundeuva. A qualidade das sementes de Myracrodruon urundeuva está relacionada com a temperatura máxima, média e mínima, umidade média e mínima, e com a precipitação. Essas variáveis de clima durante as diferentes fases fenológicas de Myracrodruon urundeuva afetam a qualidade fisiológica das sementes, sendo que, em cenários de mudanças climáticas, ocorrerá uma redução na produção de sementes desta espécie.

Palavras-chave: araçoeira-do-sertão, mudanças climáticas, germinação.
Introduction

Climatic conditions play an essential role and are related to the variability in seed production by plant species (Marcos Filho, 2015; Silva et al., 2020). Temperature variation can inhibit seedling growth, affecting all phenological phases, especially seed formation (Carvalho et al., 2017). Temperature, during seed production, acts as a synchronization factor with plant production (Schauber et al., 2002), as each physiological aspect of the plant's life cycle requires the accumulation of an amount of heat (Cruz et al., 2011)). In addition, temperature interferes with soil moisture, which also influences this production (Abrahamson and Layne 2003). So, in addition to temperature, water restriction also directly influences seed development. This occurs due to water deficit during the cell division phase that can reduce the number of seeds produced per fruit. In the phase of assimilates transfer, the water restriction determines the decrease in seeds physiological potential (Marcos Filho, 2015). This physiological potential is represented by the maturity of the seeds, from the fertilization to the maximum dry matter accumulation (Marcos Filho, 2015). Seeds with high physiological potential have greater speed in the metabolic process, providing rapid and uniform emission of the primary root in the germination process (Minuzzi et al., 2010). Studies on the influence of climatic elements on seed production have been directed at agricultural species (Singh et al., 2013), and are non-existent for seeds of forest species from the ‘Caatinga’ biome.

The Caatinga biome is the largest and one of the most diverse nuclei of the Seasonally Dry Tropical Forests (FTSS) with a seasonal climate represented by periods of long drought (Oliveira-Filho et al., 2013). The seasonality of rainfall is considered a relevant factor in the variations and distribution of plant populations in the Caatinga (Andrade et al., 2009). For this Biome, the floristic heterogeneity also reflects the adaptations to local climate and soil conditions (Fernandes and Queiroz, 2018). However, there are no studies that predict the behavior of these species against climate changes. This theme is relevant, since the Brazilian semi-arid region will be one of the most affected regions by climate change and may have direct impacts on biodiversity.

The Myracrodruon urundeuva Allemão (Anacardiaceae), known in Brazil as ‘aroeira-dosertão’ stands out among the native species of the Caatinga, with economic importance due to the use of resistant wood for rural construction (Lorenzi, 2010) and its use in pharmacology (Gomes et al., 2008). However, the exploration has been done in an extractive and disordered way, causing an impact on natural populations (Monteiro et al., 2005). This species has adaptive plasticity, which can be found in different Brazilian phytophysiognomies, from humid to dry environments (Matias et al., 2017). M. urundeuva seeds from the Caatinga biome demonstrated broad tolerance to environmental stresses, with thermal limits for germination between 7.4 and 53.3 °C and an osmotic limit of -0.6 MPa (Oliveira et al., 2019). The knowledge of the environmental conditions that interfere in the production of the seeds of this species and, consequently, in its physiological quality, constitutes a main factor for understanding the processes that threaten the production stages, the natural regeneration process and the permanence of the seed bank in the soil.

In environments with varying seasonality, it is important to study the timing of major phenological events to efficiently predict impacts caused by climate change (Alberton et al., 2019). During the dry season, in addition to losing its leaves (Griz and Machado 2001), M. urundeuva has its diaspores dispersed, germinating after the beginning of the first rains (Oliveira et al., 2019).

Within this context, the hypothesis that the climate conditions during the development of forest species are responsible for the differences in the physiological quality of the seed crops produced was tested. Thus, the objective was to determine the relationship between climatic elements and the germination of different crops of M. urundeuva seeds, as well as to predict germination according to different climatic scenarios.

Material and methods

Seed Germination Test - The M. urundeuva diaspores were harvested from parent trees located in Lagoa Grande – PE, Brazil (8° 34’13.1 ”S, 40°11’02.2” W) from 2005 to 2018. The processing was performed through pre-cleaning (manually removing wings and branches) and, subsequently the samples were submitted to the seed blower for impurities separation. The seed germination test was carried out right after beneficiation. Four replications with 50 seeds each were used. The seeds were sown in two layers of blotting paper inside ‘gerbox’ type acrylic boxes (11x11x3cm) moistened with distilled water in the

Oliveira, G. M., Angelotti, F. Marques, E. J. N., Silva, F. F. S., Pelacani, C. R., Dantas, B. F.
The seeds were incubated for 14 days in 12 hours of photoperiod, at a temperature of 25 °C (Brazil, 2013).

Climatic data - To determine the influence of climatic elements on the phenological phases of *M. urundeuva* in each production season (harvest-harvest), climatic data for the months referring to the vegetative phase (November-May), female flowers (July-August), male flowers (June-August) and fruiting (September-October) (Kill et al., 2010) were evaluated.

Climatic data for the years 2004 to 2018 were collected from the Bebedouro Automatic Agrometeorological Station (W 40 ° 22′S 09 ° 09′), belonging to Embrapa Semiárido, Petrolina - PE, Brazil, at a distance of 64.5 km of the parent trees area. The following monthly data were used: average (Tmed), maximum (Tmax), and minimum (Tmin) temperatures; average relative humidity (URmed), maximum (URmax) and minimum (URmin); global radiation (RG); wind speed (VV); precipitation (Prec) and reference evapotranspiration (Eto).

From these data, temperature and precipitation events related to the number of days were selected with: maximum temperature above 35 °C (dTmax > 35); minimum temperature above 24 °C (dTmin > 24); minimum temperature above 20 °C (dTmin > 20); average temperature above 30 °C (dTmed > 30); precipitation above two mm (dP > 2); precipitation above five mm (dP > 5); precipitation above 10 mm (dP > 10). In addition to these variables, weeks with precipitation below 20 mm (SP < 20) were selected.

Data Analysis - The germination evaluations (1 mm of visible primary root) were carried out at the end of the period of seeds soaking. The data were submitted to variance analysis and the means compared by the Sckott-Knot’s test (P < 0.05) with the aid of the AgroEstat Software. Simple linear correlation analysis was performed, in which Pearson's correlation coefficients were estimated between the germination values of the seed crops and the climate variables for each phenological phase, in the four studied replications (Barbosa and Maldonado Junior, 2012).

Multiple linear regression analysis (MLR, from Multiple Linear Regression) was used to evaluate the germination behavior in relation to climatic elements. The purpose of the multiple linear regression analysis was to develop a mathematical model in order to estimate the response of a variable, considering the values of several explanatory variables. The mathematical model of multiple linear regression was expressed by:

\[ Y = B_0 + B_1X_{1j} + B_2X_{2j} + \ldots + B_kX_{kj} + \varepsilon_j \]  

(Equation 1)

In which:
- \( Y \) represent the response variable;
- \( X_{1j} \) denote the explanatory variables;
- \( B1= \) denote the model parameters (or regression coefficients) to be estimated;
- \( \varepsilon_j \) are the random errors of the assumed independent model.

Parameter B1 represents the expected variation in response Y per unit of variation in X1, when all other explanatory variables are kept constant (Montgomery and Runger, 2008).

Multivariate Calibration Model - The multivariate calibration model was developed using the MLR method with previous selection of variables. The predictive performance of the model was assessed in the cross-validation stage. This step is normally used to evaluate the generalizability of a model, allowing to check in a more realistic way its predictive performance against a new data set.

In this present study, ten climate variables were selected by the Successive Projections Algorithm (SPA) (Araújo et al. 2001). The SPA algorithm is an interactive variable selection method developed to minimize effects of multicollinearity (presence of a high degree of correlation between variables), specifically when using MLR for the construction of calibration models. The objective is to select a representative subset of spectral variables whose information content is minimally redundant.

The selection of variables by the SPA algorithm was performed using the MATLAB software version R2015a (Mathworks, Natick, USA) and the graphical interface for MATLAB “SPA_GUI” (available at http://www.ele.ita.br/~kawakami/ spa/). The calculations related to the development of the multivariate calibration model were performed using the software The Unscrambler X version 10.5 (Camo, Oslo, Norway).

Estimated Germination for Climate Change Scenarios - Based on the mathematical model, the germination of *M. urundeuva* seeds was forecast in the scenarios RCP 2.6 and RCP 8.5 (IPCC, 2014). From the averages of the climatic data for the 2005 to 2018 harvests, the climatic...
conditions for each scenario in 2100 were estimated.

The RCP 2.6 scenario provides for the maintenance, in the period from 2080 to 2100, of approximately 400 ppm of CO₂ in the atmosphere, in addition to an increase in temperature of 1.0 °C and a decrease of 25% in precipitation. However, in a RCP 8.5 scenario, it is estimated that CO₂ concentrations are above 720 ppm, with an increase in temperature of 3.5 °C and 40% in decreasing precipitation. The relative humidity (RH) was calculated for the scenarios according to the methodology proposed by Silva et al. (2007).

Results and discussion

According to the germination test, it was observed that *M. urundeuva* seeds produced from 2005 and 2018 presented differences regarding the physiological quality according to the season/year (Table 1).

Table 1. Means of *Myracrodruon urundeuva* Allemão (Anacardiaceae) seeds germination harvested in different years.

| Harvest | Germination (%) |
|---------|-----------------|
| 2005    | 79.5 b          |
| 2006    | 89.0 a          |
| 2007    | 73.0 c          |
| 2008    | 72.0 c          |
| 2009    | 64.0 c          |
| 2010    | 83.0 b          |
| 2011    | 89.0 a          |
| 2012    | 96.5 a          |
| 2013    | 82.5 b          |
| 2014    | 84.5 b          |
| 2015    | 85.0 b          |
| 2016    | 63.5 c          |
| 2017    | 68.0 c          |
| 2018    | 64.0 c          |

CV (%) 8.42

Means followed by the same letters in columns are not different according to Skott-Knott’s test at 5% of probability.

The seeds produced in 2006, 2011 and 2012 presented a higher level of quality, with germination greater than or equal to 89%. The 2005, 2010, 2013, 2014 and 2015 harvests showed intermediate germination, with values between 79.5 and 85%. In turn, in the 2007, 2008, 2009, 2016, 2017 and 2018 harvests presented a lower physiological quality of the seeds, with germination below 73%. The seeds of the crops studied in the present work have presented this reduction in physiological quality due to climatic conditions during seed development. It is known that this forest species, as well as *Poincianella pyramidalis* (Tul.) LP Queiroz (Matias et al., 2014), *Dalbergia cearensis* Ducke (Nogueira et al., 2014) and *Dipteryx alata*. Vog (Nascimento et al., 2021) has high phenotypic plasticity, with the ability to alter their characteristics depending on environmental conditions (Lima et al., 2017). However, *M. urundeuva* is a species sensitive to the effects of low precipitation, significantly reducing the photosynthetic rate (Mesquita et al., 2018). According to Marengo et al. (2016), in the period 2015-2016 presented the maximum intensity of drought in Northeast Brazil, with rainfall rates below 600 mm. This may be one of the causes of the reduction in the quality of the seeds produced in 2016 and 2017, for example. However, seed quality may also be related to other climatic elements.

The correlation between seed germination and climatic elements during the phenological phases suggests that, during the vegetative phase, the average and maximum temperatures have a significant and negative correlation with germination, that is, the higher the Tmed, Tmax and the dTmax events> 35, dTmin> 24 and dTmed> 30, the lower the performance of the species' vegetative growth (Table 2).
Table 2. Correlation of germination of *Myracrodruon urundeuva* seeds from different harvests with average temperature (Tmed), maximum temperature (Tmax), minimum temperature (Tmin), average relative humidity (URmed), maximum relative humidity (URmax), minimum relative humidity (URmin), global radiation (RG), wind speed (VV), precipitation (Prec), reference evapotranspiration (Eto), days with maximum temperature above 35 °C (dTmax> 35), days with minimum temperature above 24 °C (dTmin> 24), days with minimum temperature above 20 °C (dTmin> 20), days with average temperature above 30 °C (dTmed> 30), days with precipitation above two mm (dP> 2), days with precipitation above five mm (dP> 5), days with precipitation above 10 mm (dP> 10), weeks with precipitation below 20 mm (sP< 20) during the phenological phases of the species.

| Elementos climáticos | Vegetativa | Flores femininas | Flores masculinas | Frutificação |
|----------------------|------------|-----------------|-----------------|-------------|
| Tmed                 | -0.28054** | -0.4141**       | -0.29860*       | -0.1882NS   |
|                      | 0.0362b    | 0.0015          | 0.0254          | 0.1648      |
| Tmax                 | -0.31543*  | -0.4726**       | -0.4184**       | -0.31310*   |
|                      | 0.0179     | 0.0002          | 0.0013          | 0.0188      |
| Tmin                 | -0.0609NS  | -0.1897NS       | -0.0345NS       | -0.2088NS   |
|                      | 0.6556     | 0.1613          | 0.8005          | 0.1224      |
| URmed                | -0.2287NS  | -0.1944NS       | -0.2596NS       | -0.32614*   |
|                      | 0.0900     | 0.1511          | 0.0534          | 0.0142      |
| URmax                | -0.0566NS  | 0.05641NS       | -0.0430NS       | 0.02920NS   |
|                      | 0.6785     | 0.6796          | 0.7531          | 0.8308      |
| URmin                | -0.1234NS  | 0.21053NS       | 0.13536NS       | -0.1714NS   |
|                      | 0.3648     | 0.1194          | 0.3199          | 0.2066      |
| RG                   | -0.2023NS  | -0.3877**       | -0.3757**       | -0.27513*   |
|                      | 0.1349     | 0.0032          | 0.0043          | 0.0401      |
| VV                   | 0.18287NS  | 0.310754*       | 0.276610*       | 0.10104NS   |
|                      | 0.1773     | 0.0198          | 0.0390          | 0.4587      |
| Prec                 | -0.0927NS  | 0.38274**       | 0.18796NS       | -0.4449**   |
|                      | 0.4970     | 0.0036          | 0.1654          | 0.0006      |
| Eto                  | -0.1180NS  | -0.30194*       | -0.3547**       | -0.1126NS   |
|                      | 0.3866     | 0.0237          | 0.0073          | 0.4087      |
| dTmax>35             | -0.5705**  | -0.32885*       | -0.4301**       | -0.3770**   |
|                      | < 0.0001   | 0.0133          | 0.0009          | 0.0042      |
| dTmin>24             | -0.4704**  | -               | -               | -0.2323NS   |
|                      | 0.0003     |                |                | 0.0849      |
| dTmin>20             | -0.0582NS  | -0.0019NS       | -0.0129NS       | -0.1174NS   |
|                      | 0.6699     | 0.9887          | 0.9247          | 0.3890      |
| dTmed>30             | -0.5583**  | -               | -               | -0.2197NS   |
|                      | < 0.0001   |                |                | 0.1038      |
| dP>2                 | -0.1144NS  | 0.327558*       | 0.26240NS       | -0.27397*   |
|                      | 0.4012     | 0.0137          | 0.0507          | 0.0410      |
| dP>5                 | -0.1970NS  | 0.299675*       | 0.25065NS       | -0.28003*   |
|                      | 0.1457     | 0.0248          | 0.0624          | 0.0366      |
| dP>.10               | -0.2593NS  | 0.25659NS       | 0.14875NS       | -0.4657**   |
|                      | 0.0536     | 0.0563          | 0.2739          | 0.0003      |
| sP<20                | 0.21016NS  | 0.10613NS       | -0.2130NS       | 0.46566**   |
|                      | 0.1200     | 0.4363          | 0.1150          | 0.0003      |

*a*Correlation coefficient; *b*probability; NS not significant correlation; *significant correlation at 5%; significant correlation at 1%.

Oliveira, G. M., Angelotti, F. Marques, E. J. N., Silva, F. F. S., Pelacani, C. R., Dantas, B. F.
In the formation phase of female flowers, the temperatures $T_{med}$ and $T_{max}$ also showed a significant and negative correlation, in addition to RG, Eto, $dT_{max} > 35$. However, VV, Prec, $dP > 2$ and $dP > 5$ showed a significant and positive correlation with seed germination. For male flowers, $T_{med}$, $T_{max}$, RG, ETo and $dT_{max} > 35$ correlated negatively with germination, and VV provided a positive correlation. Finally, in fruiting, $T_{max}$, URmed, RG, $dT_{max} > 35$ and all variables related to precipitation (Prec, $dP > 2$, $dP > 5$ and $dP > 10$) presented a negative correlation with germination, except $sP < 20$ which correlated positively (Table 2).

Climatic elements can determine or restrict the occurrence of phenological phases (Japiassú et al., 2016). The heat accumulated during the phenological cycle directly controls the phenological phases, interfering in plant development (Forrest and Miller-Rushing, 2010).

*M. urundeuva* fruits grow in months with low rainfall (below 30 mm per month), relative humidity below 60% and high wind speed (Kill et al., 2010). This can be explained by the synchrony of pollinating agents to environmental stimuli (Müller and Schmitt, 2018) and also by the Wind, favoring the spread of propagules, facilitating later germination and the establishment of seedlings during the rainy season (Lopes et al., 2010). As can be seen in Table 2, the correlation between average humidity and germination during fruiting was negative. This data corroborates with the data observed in the field, inferring that the high relative humidity affects the fruiting index of *M. urundeuva*.

The knowledge regarding the relationship of climatic elements in each phenological phase of *M. urundeuva* elucidates the interaction between the environment and the physiological quality of the species' seeds. Thus, the existence of correlation indicate a linear association between germination and climate variables, and the positive correlation indicated that the two variables responded equally, which means that high values of a variable corresponded to high values of another variable and the negative correlation represents that high values of one variable corresponded to low values of the other variable (Figueiredo Filho and Silva Junior, 2009).

The variables that showed the greatest adjustment in the equation were: maximum temperature in the vegetative phase ($T_{max vg}$), minimum temperature in the vegetative phase ($T_{min vg}$), precipitation in the vegetative phase (Precvg), average humidity in the vegetative phase (Urmedvg), average temperature in the female flower formation phase ($T_{med ff}$), minimum temperature in the female flower formation phase ($T_{min ff}$), minimum temperature in the male flower formation phase ($T_{min fm}$), minimum humidity in the male flower formation phase ($U_{min fm}$), minimum temperature in the fruiting phase ($T_{min fr}$) and precipitation in the fruiting phase (Precfr) by the SPA algorithm. Figure 1 shows that there is no strong evidence of departures from the assumption of normality for errors, that is, there is a good accommodation of the points within the regression generated for the adjusted model. The values of the correlation coefficient of the model ($R^2 = 0.80$) and of the cross-validation ($R^2 = 0.67$) are satisfactory, indicating the validity of the model to estimate the germination values in climate change scenarios.

![Figure 1](image_url)

Figure 1. Relationship between the evaluated (real values) percentage of germination of *Myracrodruon urundeuva* Allemão (Anacardiaceae) seeds and the values predicted by the obtained calibration model, in the calibration steps (symbols in blue) and cross-validation (symbols in red).

The mathematical model confirms the influence of temperature on all phenological phases of *M. urundeuva*. In the vegetative phase (vg), temperatures $T_{max vg}$ and $T_{min vg}$ and URmedvg negatively influenced the quality of seed crops. However, in this phenological phase, precipitation had a positive influence. In the female flower formation phase, it was found that the minimum air temperature ($T_{min ff}$) had a negative relationship,
as well as in the fruiting phase. In fruiting, precipitation also showed the same behavior.

The severe impacts on plant productivity are increasing due to the direct and indirect effects of abiotic stresses (Raza et al., 2019). The climate is one of the main factors that condition the behavior of plants, and the model for the northeastern semiarid predicts this variability in the production of physiological quality seeds (Figure 2). Thus, it becomes more accurate and efficient in future climate analysis.

The reduction in the physiological quality of *M. urundeuva* seeds in the scenarios RCP 2.6 and RCP 8.5 in 2100 can be verified through the germination values presented in Figure 2. This reduction is directly related to changes in temperature, precipitation and humidity during the different phenological phases, which directly influenced the quality of the produced seeds.

![Figure 2. Evaluated germination (real) and estimated for the evaluated years of Myracrodruon urundeuva Allemão (Anacardiaceae) and climatic scenarios for 2100. Vertical bars represented or average mean standard.](image)

As the climate is directly related to seed production, there is a notable concern regarding future scenarios. Uncertainties about impacts for different ecosystems were reported by Souza and Oyama, 2011. A more complete description of the climatic condition in which the parent plants are found, coupled with an effective storage protocol for the produced seeds, may assist in greater longevity of this material (Zinsmeister et al., 2020). For the Northeast of Brazil, the probability that events such as drought and temperature increase will intensify in the coming years points to the relevance of studies like this, in order to seek adaptation measures for the regeneration of *M. urundeuva*, reducing the vulnerability of this species.

**Conclusions**

Precipitation, temperature and air humidity during the different phenological phases affect the physiological quality of *M. urundeuva* seeds. In climate change scenarios, there will be a reduction in the production of seeds of this species.

**Acknowledgments**

The authors would like to thank the financial support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financing Code 171 15/2014; National Council for Scientific and Technological Development - Brazil (CNPq) - Financing Code REF423143 / 2016-6; Brazilian Agricultural Research Corporation - Brazil (Embrapa).

**References**

Abrahamson, W.G., Layne J.N., 2003. Long-term patterns of acorn production for five oak species in xeric Florida uplands. Ecology 84, 2476-2492.

Alberton, B., Torres, R.S., Silva, T.S.F., Rocha, H.R.D., Moura, M.S.B., Morellato, L.P.C., 2019. Leafing patterns and drivers across seasonally dry tropical communities. Remote Sensing, 11 2267.

Andrade, M.V.M., Andrade A.P., Silva, D.S., Alcântara Bruno, R.L., Guedes, D.S., 2009. Levantamento florístico e estrutura fitossociológica do estrato herbáceo e subarbustivo em áreas de caatinga no Cariri paraibano. Revista Caatinga 22, 229-237.

Araújo, M.C.U., Saldanha, T.C.B., Galvão, R.K.H., Yoneyama, T., Chame, H.C., Visani, V., 2001. The successive projections algorithm for variable selection in spectroscopy multicomponent analysis. Chemometrics and Intelligent Laboratory Systems 57, 65-73.

Barbosa, J.C., Maldonado Junior, W., 2012. AgroEstat – Sistema de análises estatísticas de ensaios agronômicos [AgroEstat - analysis system for statistics of agronomic trials], Versão 1.0. Jaboticabal, Brazil: UNESP.

Brasil, Ministério da Agricultura, Pecuária e Abastecimento, 2009. Regras para análise de sementes, p. 395. Secretaria de Defesa Agropecuária. Brasília: MAPA, SDA, 395.

Brasil, Ministério da Agricultura, Pecuária e Abastecimento, 2013. Instruções para análise de
sementes florestais, p. 97. Secretaria de Defesa Agropecuária. Brasília: MAPA/ACS.

Carvalho, J.N.S., Bezerra, J.A., Reis, D.S., Guimarães, C.C., Santos, I.E.A., 2017. Simulação do efeito da variação da temperatura ambiente na germinação de variedades de milho. Journal of Environmental Analysis and Progress 2, 266-273.

Cruz, J.C., 2011. Milho: o produtor pergunta, a Embrapa responde, p. 338. Coleção 500 perguntas, 500 respostas. EMBRAPA/Brasília.

Fernandes, M.F., Queiroz, L.P., 2018. Vegetação e flora da Caatinga. Ciência e Cultura 70, 51-56.

Figueiredo Filho, D.B., Silva Júnior, J.A.D., 2009. Desvendando os Mistérios do Coeficiente de Correlação de Pearson (r). Revista Política Hoje 18, 115-146.

Forrest, J., Miller-Rushing, A.J., 2010. Toward a synthetic understanding of the role of phenology in ecology and evolution. Philosophical Transactions of the Royal Society of London B: Biological Sciences 365, 3101-3112.

Gomes, E.C., Barbosa, J., Vilar, F.C., Perez, J., Vilari, R., Dias, T., 2008. Plantas da caatinga de uso terapêutico: levantamento etnobotânico. Engenharia Ambiental: Pesquisa e Tecnologia 5, 74-85.

Griz, L.M.S., Machado, I.C.S., 2001. Fruiting phenology and seed dispersal syndromes in caatinga, a tropical dry forest in the northeast of Brazil. Journal of Tropical Ecology, 17, 303-321.

IPCC., 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds Core Writing Team, R. K. Pachauri, L. A. Meyer), p.151 IPCC, Geneve.

Japiasu, A., Lopes, K.P., Dantas, J.G., Nóbrega, J.S., 2016. Fenologia de quatro espécies arbóreas da Caatinga no Semiárido paraibano. Revista Verde de Agroecologia e Desenvolvimento Sustentável 11, 34-43.

Kill, L.H.P., Martins, C.D.V., Silva, P.P., 2010. Biologia reprodutiva de duas espécies de Anacardiaceae da caatinga ameaçadas de extinção, pp. 337-364 in: Albuquerque, U.P., Moura, A.N., Araújo, E.L. Biodiversidade, potencial econômico e processos ecosistêmicos em ecossistemas nordestinos. Bauru, São Paulo, Brazil.

Lima, N.R.W.L., Sodré, G.A., Lima, H.R.R., Paiva, S.R., Lobão, A.Q., Coutinho, A.J., 2017. Plasticidade fenotípica. Revista de Ciência Elementar 5, 1-7.

Lopes, S.D.F., Oliveira, A.P.D., Neves, S.B., Schiavini I., 2010. Dispersão de sementes de uruvalheira (Platypodium elegans VOG.) (Fabaceae) em um cerradão, Uberlândia-MG. Revista Árvore 34, 807-813.

Lorenzi, H., 2010. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil, p. 384 in: 5ª ed. Nova Odessa, Instituto Plantarum.

Marcos Filho, J., 2015. Fisiologia de sementes de plantas cultivadas, p. 660 in: 2.ed. Piracicaba: FEALQ.

Marengo, J.A., Cunha, A.P., Alves, L.M.A., 2016. A seca de 2012-15 no semiárido do Nordeste do Brasil no contexto histórico. Climanálise 3, 1-6.

Matias, J.R., Ribeiro, R.C., Oliveira, G.M., Affonso, I.B., Silva, T.B., Costa, D.C.C., Bispo, J.S., Mendes, R.B., Dantas, B.F., 2014. Temperatura limitante à germinação de sementes de cauliflora e catingueira-verdadeira. Informativo Abrates 24, 87.

Matias, R.A.M., Ferreira, B.S., Soares, T.S., 2017. Quantificação de biomassa e estimativa de estoque de carbono de indivíduos de aroeira em um fragmento de floresta estacional decidual. Revista da Universidade Vale do Rio Verde 15, 651-657.

Mesquita, A.C., Dantas, B.F., Cairo, P.A.R., 2018. Ecophysiology of caatinga native species under semi-arid conditions. Bioscience Journal 34, 81-89.

Minuzzi, A., Braccini, A.D.L., Rangel, M.A.S., Scapim, C.A., Barbosa, M.C., Albrecht, L.P., 2010. Qualidade de sementes de quatro cultivares de soja, colhidas em dois locais no Estado do Mato Grosso do Sul. Revista Brasileira de Sementes 32, 176-185.

Monteiro, J.M., Lins Neto, E.M.F., Amorim, E.L.C., Strattmann, R.R., Araújo, E.L., Albuquerque, U.P., 2005. Teor de taninos em três espécies medicinais arbóreas simpátricas da caatinga. Revista Árvore 29, 999-1005.

Montgomery, D.C., Runger, G.C., 2008. Estatística aplicada e probabilidade para engenheiros. In: 2. ed. Rio de Janeiro: LTC.

Müller, A., Schmitt, J.L., 2018. Phenology of Guarea macrophylla Vahl (Meliaceae) in subtropical riparian forest in southern Brazil. Brazilian Journal of Biology 78, 187-194.

Nascimento, J.C., Vilarinho, M.K.C., Caldeira, D.S.A., Antoniacomi, L.A.M., Oliveira, A.J., Oliveira, T.C., Silva, G.F., Oliveira A.S., 3696

Oliveira, G. M., Angelotti, F. Marques, E. J. N., Silva, F. F. S., Pelacani, C. R., Dantas, B. F.
Barelli, M.A.A., Luz, P. B., 2021. Maturação e qualidade fisiológica das sementes de cumbaru em função do período de coleta dos frutos. Research, Society and Development 10, 1-10.

Oliveira, G.M., Silva, F.F.S., Araujo, M.N., Costa, D.C.C., Gomes, S.E.V., Matias, J.R., Angelotti, A., Cruz, C.R.P., Seal, C.E., Dantas, B.F., 2019. Environmental stress, future climate, and germination of Myracrodruon urundeuva seeds. Journal of Seed Science 41, 32-43.

Oliveira-Filho, A.T., Cardoso, D., Schrire, B.D., Lewis, G.P., Pennington, R.T., Brummer, T.J., Rotella, J., Lavin, M., 2013. Stability structures tropical woody plant diversity more than seasonality: insights into the ecology of high legume-succulent-plant biodiversity. South African Journal of Botany 89, 42-57.

PBMC, 2013. Contribuição do Grupo de Trabalho 1 ao Primeiro Relatório de Avaliação Nacional do Painel Brasileiro de Mudanças Climáticas. Sumário Executivo GT1. PBMC, Rio de Janeiro, Brasil. 24 p.

Raza, A., Razaq, A., Mehmood, S.S., Zou, X., Zhang, X., Lv Yand Xu, J., 2019. Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review. Plants, 8, 34.

Schauer, E.M., Kelly, D., Turchin, P., Simon, C., Lee, W.G., Allen, R.B., Payton, I.J., Wilson, P.R., Cowan, P.E., Brockie, R.E., 2002. Masting by eighteen New Zealand plant species: the role of temperature as a synchronizing cue. Ecology 83, 1214-1225.

Silva, G.A., Pacheco, M.V., Luz, M.N., Nonato, E.R.L., Delfino, R.D.C.H., Pereira, C. T., 2020. Fatores ambientais na germinação de sementes e mecanismos de defesa para garantir sua perpetuação. Research, Society and Development, 9, 1-12.

Silva, T.G., Moura. M.S., Sá, I.I., Zolnier, S., Turco, S.H., Justino, F., Carmo, J.F.A., Souza, L.S., 2009. Impactos das mudanças climáticas na produção leiteira do Estado de Pernambuco: análise para os cenários B2 e A2 do IPCC. Revista Brasileira de Meteorologia 24, 489-501.

Silva, T.G.F., Zolnier, S., Moura, M.S.B., Sediyama, G.C., 2007. Estimativa e espacialização da umidade relativa do ar para os estados de Alagoas, Bahia e Sergipe. Revista Brasileira de Agrometeorologia 15, 1-11.

Singh, R.P., Prasad, P.V.V., Reddy, K.R., 2013. Impacts of changing climate and climate variability on seed production and seed industry. Advances in Agronomy 118, 49-110.

Souza, D.C., Oyama, M.D., 2011. Climatic consequences of gradual desertification in the semi-arid area of Northeast Brazil. Theoretical and Applied Climatology 103, 345-357.

Zinsmeister, J., Leprince, O., Buitink, J., 2020. Molecular and environmental factors regulating seed longevity. Biochemical Journal 477, 305-323.