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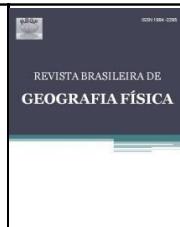
Climate and the *Myracrodruon urundeuva* Allemão seed production

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A B S T R A C T

The seed physiological quality is related with climate variation during development. Thus, the aim of this study was to determinate the relation among climatic factors and germination of *M. 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 *M. urundeuva*. The simple linear correlation and the multiple linear regression model were applied to determine the influence of climatic elements on the production of *M. 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 *M. 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 *M. urundeuva*. The quality of *M. urundeuva* seeds is related to the maximum, average and minimum temperature, average and minimum humidity, and precipitation. These climate variables during the different phenological phases of *M. 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: aroeira-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 *M. 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 Semiárido, para determinar a influência das condições climáticas nas fases vegetativa, flores femininas e masculinas e da frutificação de *M. 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 *M. 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 *M. 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 *M. urundeuva*. A qualidade das sementes de *M. 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 *M. 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: aroeira-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 accumultion (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 semiarid 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-do-sertão' 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

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proportion of 2.5 times the paper weight (Brasil, 2009). 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 Semiarid, 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:

$$Y_j = B_0 + B_1 X_{1j} + B_2 X_{2j} + ... + B_K X_{Kj} + \varepsilon_j$$
(Equation 1)

In which:

Y_j = represent the response variable;

X_{1j} = denote the explanatory variables;

$B1$ = denote the model parameters (or regression coefficients) to be estimated;

ε_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 interative 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

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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 CO_2 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 CO_2 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 aaccording 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 testa t 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).

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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 (SD> 5), days with precipitation above 10 mm (SD> 10), weeks with precipitation below 20 mm (SD <20) during the phenological phases of the species.

Elementos climáticos	Fases fenológicas			
	Vegetativa	Flores femininas	Flores masculinas	Frutificação
Tmed	**-0,28054[a]***	**-0,4141****	**-0,29860***	-0,1882NS
	0,0362[b]	**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%.

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In the formation phase of female flowers, the temperatures Tmed and Tmax also showed a significant and negative correlation, in addition to RG, Eto, dTmax> 35. However, VV, Prec, dP> 2 and dP> 5 showed a significant and positive correlation with seed germination. For male flowers, Tmed, Tmax, RG, ETo and dTmax> 35 correlated negatively with germination, and VV provided a positive correlation. Finally, in fruiting, Tmax, URmed, RG, dTmax> 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 valuesof a variable corresponded to high values of another variable and the negative correlation represents that high valuesof 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 (Tmaxvg), minimum temperature in the vegetative phase (Tminvg), precipitation in the vegetative phase (Precvg), average humidity in the vegetative phase (Urmedvg), average temperature in the female flower formation (Tmedff), minimum temperature in the female flower formation phase (Tminff), minimum temperature in the male flower formation phase (Tminfm), minimum humidity in the male flower formation phase (Uminfm), minimum temperature in the fruiting phase (Tminfr) 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.
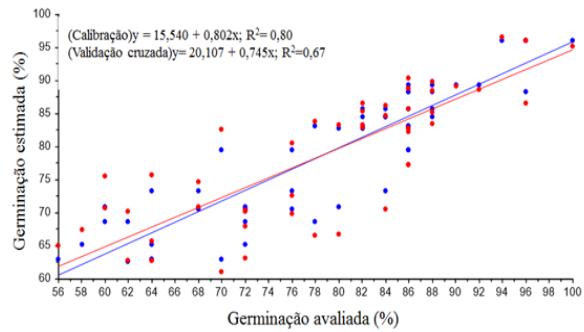

Figure 1. Relationship between the evaluated (real values) percentage of germination of (*Myracrodruon urundeuva* Allemão (Anacardiaceae)) seeds and the values predicted by the obtained calibration model, in the calibration steps (symbols in blue) and cross-validation (symbols in red).

The mathematical model confirms the influence of temperature on all phenological phases of *M. urundeuva*. In the vegetative phase (vg), temperatures Tmaxvg and Tminvg 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 (Tminff) had a negative relationship,

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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.
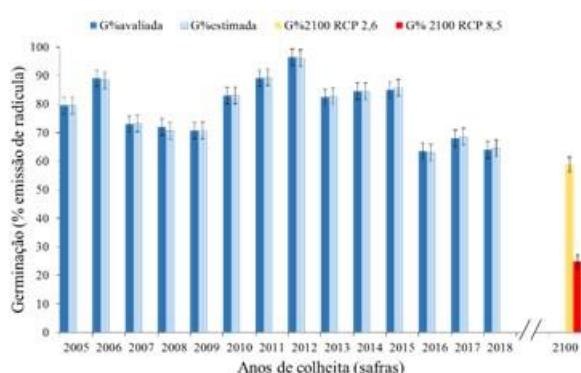

Figure 2. Evaluated germination (real) and estimated for the evaluated years of *Myracrodruon urundeuva* Allemão (Anacardiaceae) and climatic scenarios for 2100. Vertical bars represented or average mean standard.

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

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