Revista
ÁRVORE
ISSN 1806 – 9088

Scientific Article

HOW MIGHT CLIMATE CHANGE AFFECT THE DISTRIBUTION OF VELAME *Croton heliotropiifolius*?

Davi Raftopoulos Oliveira[2*], Carlos Henrique Souto Azevedo[2], Thais Ribeiro Costa[3] and André Rodrigo Rech[4]

1 Received on 24.03.2024 accepted for publication on 31.07.2024.

2 Universidade Federal dos Vales do Jequitinhonha e Mucuri, Programa de Pós-Graduação em Ciência Florestal; Diamantina, MG, Brasil. E-mail: <daviraftopoulosoliveira@gmail.com> and <carlos.azevedo@ufvjm.edu.br>.
3 Universidade Federal do Tocantins, Departamento de Engenharia Florestal; Gurupi, TO, Brasil. E-mail: <thaisribeiro.florestal@gmail.com>.
4 Universidade Federal dos Vales do Jequitinhonha e Mucuri, Programas de Pós-Graduação em Biologia Animal, Ciência Florestal e Estudos Rurais; Diamantina, MG, Brasil. E-mail: <andre.rech@ufvjm.edu.br>.
*Corresponding author.

ABSTRACT

Velame, *Croton heliotropiifolius*, is an important plant for the production of special honeys in the Brazilian semi-arid region. However, the distribution of many plant species such as velame might be affected by climate change. The aim of this study was to estimate the distribution of *C. heliotropiifolius* in Brazil under different climate change scenarios using predictive species distribution modeling. We made estimates for the years 2050 and 2070, in pessimistic and optimistic climate change scenarios using climate data from worldclim.org and species occurrence records from specieslink.net and gbif.org. Using the MaxEnt algorithm and the wallace package, we conducted predictive distribution modeling with occurrence and climate data associated with GIS. We divided areas according to their suitability for the occurrence of velame - inadequate, low suitability, medium suitability and high suitability. We then compared the predicted values with present data. In all future scenarios, the areas of low and medium suitability grew by more than 100% compared to the present. The areas of high suitability, on the other hand, undergo a slight reduction in the optimistic scenarios of 2050 and 2070, and in the pessimistic scenario for 2050. However, the pessimistic scenario for 2070 indicates a 19.6% increase in area compared to the present. This shows that in the pessimistic scenario for climate change, occurrence area under optimal conditions would shrink in 2050 and then expand in 2070. Although the results may sound promising for this species, they also indicate an expansion of the semi-arid climate, which may not necessarily benefit honey production.

Keywords: Predictive distribution modeling; Velame; MaxEnt

How to cite:
Oliveira, D. R., Azevedo, C. H. S., Costa, T. R., & Rech, A. R. (2024). How might climate change affect the distribution of velame *Croton heliotropiifolius*?. *Revista Árvore, 48*(1). https://doi.org/10.53661/1806-9088202448263766

COMO A MUDANÇA DO CLIMA PODE AFETAR A DISTRIBUIÇÃO DE *Croton heliotropiifolius*?

RESUMO – *Croton heliotropiifolius* é uma planta muito importante para a produção de méis especiais no semiárido brasileiro. No entanto, a distribuição de muitas espécies vegetais pode ser afetada pela mudança do clima. O objetivo deste trabalho foi estimar a distribuição de *C. heliotropiifolius* no território brasileiro em diferentes cenários de mudança do clima por meio da modelagem preditiva de distribuição de espécies. As estimativas foram feitas para os anos 2050 e 2070, em cenários pessimistas e otimistas de mudança do clima com dados climáticos obtidos do site worldclim.org, registros de ocorrência da espécie retirados do specieslink.net e gbif.org. Com o uso do algoritmo MaxEnt e do pacote wallace, foi realizada a modelagem preditiva de distribuição utilizando dados de ocorrência e climáticos, associados a SIG. As áreas foram divididas de acordo com adequabilidade de ocorrência, sendo elas inadequada, baixa adequabilidade, média adequabilidade e alta adequabilidade. Tais valores foram comparados com os valores obtidos para o presente. Em todos os cenários futuros, as áreas de baixa e média adequabilidade cresceram mais de 100% em relação ao presente. Já as áreas de alta adequabilidade passariam por uma leve redução nos cenários otimistas 2050 e 2070, e no cenário pessimista para 2050. Já o cenário pessimista para 2070, indica um aumento de 19,6% de área em relação ao presente. Isto mostra que no cenário pessimista para a mudança do clima, a área da planta em condições ótimas irá reduzir em 2050 e em seguida se expandir em 2070. Embora os resultados possam soar promissores para esta espécie é importante perceber que eles indicam uma expansão do clima semiárido e isso pode não necessariamente representar um resultado interessante para a produção de mel.

Palavras-Chave: Modelagem preditiva de distribuição; Velame; MaxEnt

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) published its Sixth Assessment Report in 2021, concluding that due to prominent greenhouse gas emissions by human activities, the global mean temperature will rise by 1.5°C in the next 20 years, which could cause irreversible losses of biodiversity in ecosystems (IPCC, 2021), affecting the distribution of many plant species, in some cases to extinction (Silva et al., 2022). The effect of this change is evident in desert and semi-arid vegetation, which already experiences an increase in aridity (IPCC, 2021). In the Brazilian semi-arid region, changes in temperature and precipitation put the entire region at risk of desertification, causing frequent and severe droughts (Tavares et al., 2019).

In recent years, human activities have intensified significantly; changes in land use and climate change have resulted in a decrease in the population, geographical distribution and diversity of plant and animal species (Steffen et al., 2015). Plants are estimated to be affected by rising temperatures and changing rainfall patterns, favoring the spread of pests and pathogens, likely leading to greater use of pesticides (Delcour et al., 2015). In addition to climate change, deforestation is another factor leading to environmental degradation and the loss of species in the semi-arid region, affecting the local economy (de Sousa Vieira et al., 2022).

Croton heliotropiifolius Kunth (Euphorbiaceae), popularly known as velame, is a well-distributed plant species in the Brazilian semi-arid region. Most records of this species are from the northeastern Brazilian states and northern Minas Gerais, with some individuals from other regions of the country (GBIF, 2022; CRIA, 2022). Velame honey, when produced by stingless bees (Meliponini), contains polyphenols and antioxidant properties (Sousa et al., 2016), making velame a species of great socioeconomic importance due to its melliferous potential (Oliveira et al., 2022). This plant is an important source of nectar for European bees (*Apis mellifera*) and is the floral base for the production of special velame honey (Oliveira et al., 2021).

Given the economic and ecological importance of velame, as well as its potential for producing special honeys, knowing how vulnerable this species is to climate change is essential. One way of estimating the future distribution of populations in pessimistic and optimistic climate change scenarios is to use predictive distribution modeling to predict the occurrence of a species using computational methods that combine georeferenced occurrence points of the target species with environmental variables (Anderson et al., 2003).

In this work, we asked: what changes could climate change cause in the distribution of *Croton heliotropiifolius*?

Thus, the aim of this study was to estimate the distribution of *C. heliotropiifolius* in Brazil under different climate change scenarios using predictive species distribution modeling. To answer the main question, we raised the following research questions: a) Is it possible to predict the environmental suitability of the species using modeling tools? b) Can the distribution of *C. heliotropiifolius* be affected by climate change?

2. MATERIAL AND METHODS

Predictive distribution modeling is an important tool for estimating the effects of climate change on species distribution. Given the possible scenarios, it is possible to estimate which areas a species may occupy in the future (Costa et al., 2023).

2.1 Target species

Croton heliotropiifolius Kunth (Figure 1) is an Euphorbiaceae shrub, distributed from Brazil to Panama (Silva et al., 2010; Govaerts, et al., 2000). Most of the records of *C. heliotropiifolius* are located in the Brazilian semi-arid region, an area that encompasses the northeast of the country and the north of the state of Minas Gerais, whose Thornthwaite aridity index reaches up to 0.5, annual precipitation below 800 mm and drought risk above 60% (SUDENE, 2021). The reproductive biology of assemblages of different species of *Croton* L showed synchronous flowering, pollinator sharing and seed formation via interspecific crossing (Santos, 2016).

Figure 1. Photograph of *Croton heliotropiifolius* (Source: beekeeper Márcio Alves da Silva)

Figura 1. Fotografia de *Croton heliotropiifolius* (Fonte: apicultor Márcio Alves da Silva)

2.2 Species occurrence data

First, we downloaded georeferenced data for *C. heliotropiifolius* (Euphorbiaceae) in CSV format from the Global Biodiversity Information Facility (GBIF, 2022) and Species Link (CRIA, 2022) databases. We collected 2562 occurrence points from the Global Biodiversity Information Facility and 2636 from Species Link. The occurrence data were merged into a spreadsheet from which repeated points were excluded. In the next step, using GIS tools, records with inconsistencies such as: records located at sea, duplicate or dubious coordinates, or geographical inaccuracy, were removed. The number of points used to build the model after data cleaning was 1856. In the next step, points were rarefied to reduce spatial autocorrelation, which can occur due to occurrence points too close together (Costa et al., 2023). This procedure is necessary to ensure compatibility with the resolution of the climatic variables and to remove the sampling biases present in the occurrence records, thus generating better quality models (Boria et al., 2014; Leitão et al., 2011). The rarefaction was done with 5-km buffers between points. After this stage, the total number of *C. heliotropiifolius* occurrence points rose to 1775.

2.3 Predictive modeling

Predictive species distribution modeling is a method that estimates the area of occurrence of a species using algorithms that extrapolate environmental characteristics from the known locations of the species current occurrence (Giannini et al., 2012). The model is created by combining georeferenced occurrence data with environmental variables such as temperature, precipitation, elevation and vegetation (Anderson et al., 2003). The use of climate variables based on projections for future years makes it possible to obtain the species distribution area for different periods, using pessimistic and optimistic climate change scenarios (Phillips et al., 2006).

2.4 Environmental data

We obtained climate data from WorldClim (Hijmans et al., 2005), with bioclimatic variables referring to mean values between the years 1972 and 2000 in a spatial resolution of 2.5 minutes, equivalent to 5 km at the equator, in TIFF format. Each layer refers to a climate variable derived from temperature and precipitation (Table 1). These data were added to the MaxEnt algorithm (Phillips et al., 2006) along with the occurrence points to define the most suitable variables for modeling.

Table 1. Table with the description of climatic variables (Source: Adapted from Hijmans et al., 2005)

Tabela 1. Tabela com a descrição das variáveis climáticas (Fonte: Adaptado de Hijmans et al., 2005)

Variable	Description	Measurement Unit
bio1	Mean annual temperature	°C
bio2	Mean diurnal temperature variation	°C
bio3	Isothermal	dimensionless
bio4	Temperature seasonality	dimensionless
bio5	Maximum temperature of the warmest month	°C
bio6	Minimum temperature of the coldest month	°C
bio7	Annual temperature variation	°C
bio8	Mean temperature of the wettest quarter	°C
bio9	Mean temperature of the driest quarter	°C
bio10	Mean temperature of the warmest quarter	°C
bio11	Mean temperature of the coldest quarter	°C

Cont...

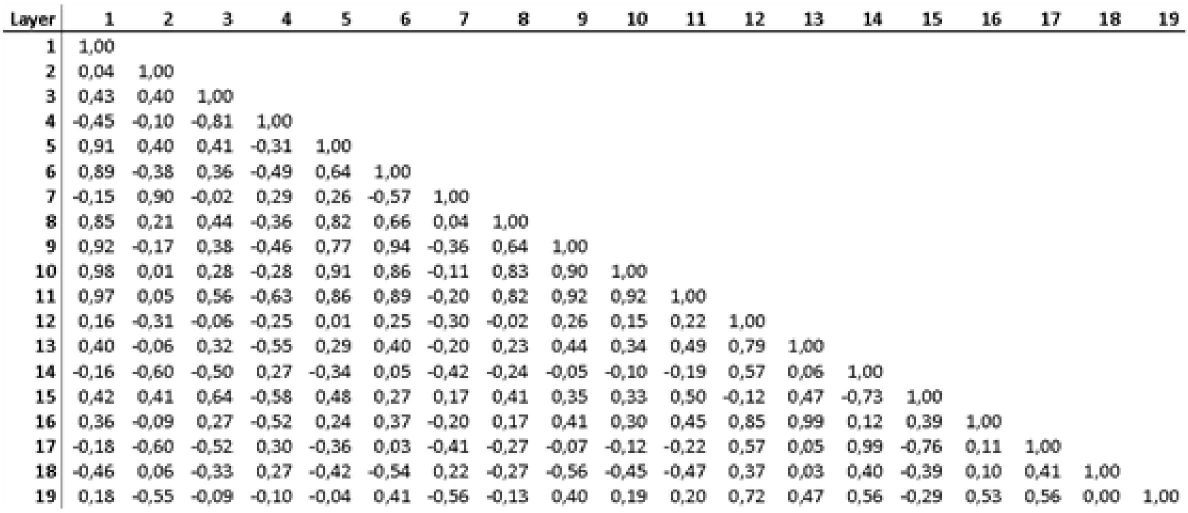
Cont...

Variable	Description	Measurement Unit
bio12	Annual precipitation	mm
bio13	Precipitation of the wettest month	mm
bio14	Precipitation of the direst month	mm
bio15	Precipitation seasonality	dimensionless
bio16	Precipitation of the wettest quarter	mm
bio17	Precipitation of the driest quarter	mm
bio18	Precipitation of the warmest quarter	mm
bio19	Precipitation of the coldest quarter	mm

For better model performance, we ran Pearson's correlation test to assess multicollinearity or autocorrelation between predictor variables, aiming to remove variables that overlap in explaining another variable (Costa et al., 2023; Fernandes et al., 2018), as shown in Table 2 (Correlation matrix). All variables with a correlation of more than 70% (r<0.7) were excluded. After this procedure, 8 out of 19 variables remained: bio3, bio4, bio7, bio12, bio15, bio17 and bio18. Of the eight variables, the ones with the highest percentage contribution combined are bio4, bio6, bio7 and bio12, which together contribute 98.7% (Table 3). The response curves for these variables can be seen in Figure 2.

Table 2. Correlation matrix (Source: the author)

Tabela 2. Matriz de correlação (Fonte: o autor)



Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1,00																		
2	0,04	1,00																	
3	0,43	0,40	1,00																
4	-0,45	-0,10	-0,81	1,00															
5	0,91	0,40	0,41	-0,31	1,00														
6	0,89	-0,38	0,36	-0,49	0,64	1,00													
7	-0,15	0,90	-0,02	0,29	0,26	-0,57	1,00												
8	0,85	0,21	0,44	-0,36	0,82	0,66	0,04	1,00											
9	0,92	-0,17	0,38	-0,46	0,77	0,94	-0,36	0,64	1,00										
10	0,98	0,01	0,28	-0,28	0,91	0,86	-0,11	0,83	0,90	1,00									
11	0,97	0,05	0,56	-0,63	0,86	0,89	-0,20	0,82	0,92	0,92	1,00								
12	0,16	-0,31	-0,06	-0,25	0,01	0,25	-0,30	-0,02	0,26	0,15	0,22	1,00							
13	0,40	-0,06	0,32	-0,55	0,29	0,40	-0,20	0,23	0,44	0,34	0,49	0,79	1,00						
14	-0,16	-0,60	-0,50	0,27	-0,34	0,05	-0,42	-0,24	-0,05	-0,10	-0,19	0,57	0,06	1,00					
15	0,42	0,41	0,64	-0,58	0,48	0,27	0,17	0,41	0,35	0,33	0,50	-0,12	0,47	-0,73	1,00				
16	0,36	-0,09	0,27	-0,52	0,24	0,37	-0,20	0,17	0,41	0,30	0,45	0,85	0,99	0,12	0,39	1,00			
17	-0,18	-0,60	-0,52	0,30	-0,36	0,03	-0,41	-0,27	-0,07	-0,12	-0,22	0,57	0,05	0,99	-0,76	0,11	1,00		
18	-0,46	0,06	-0,33	0,27	-0,42	-0,54	0,22	-0,27	-0,56	-0,45	-0,47	0,37	0,03	0,40	-0,39	0,10	0,41	1,00	
19	0,18	-0,55	-0,09	-0,10	-0,04	0,41	-0,56	-0,13	0,40	0,19	0,20	0,72	0,47	0,56	-0,29	0,53	0,56	0,00	1,00

The present climate data refer to the period between 1970 and 2000. The projections for the future correspond to the Representative Concentration Pathways (RCPs) for greenhouse gases, developed by the Intergovernmental Panel on Climate Change (IPCC, 2014). These include pessimistic and optimistic scenarios for the years 2050 and 2070. In the optimistic scenarios, RCP is 2.6, which represents an increase of less than 1°C in the global mean temperature (Matear and Lenton, 2017). In the pessimistic scenarios, RCP is 8.5, with an increase of more than 3ºC.

Table 3. Table with the remaining variables in ascending order of contribution percentage (Source: the author)

Tabela 3. Tabela com as variáveis restantes em ordem crescente de porcentagem de contribuição (Fonte: o autor)

Variable	Description	Measurement Unit	Percentage of contribution
bio6	Minimum temperature of the coldest month	°C	42.5
bio4	Temperature seasonality	dimensionless	34.8
bio7	Annual temperature variation	°C	11.4
bio12	Annual precipitation	mm	10
bio17	Precipitation of the driest quarter	mm	0.8
bio15	Precipitation seasonality	dimensionless	0.4
bio18	Precipitation of the warmest quarter	mm	0
bio3	Isothermal	dimensionless	0

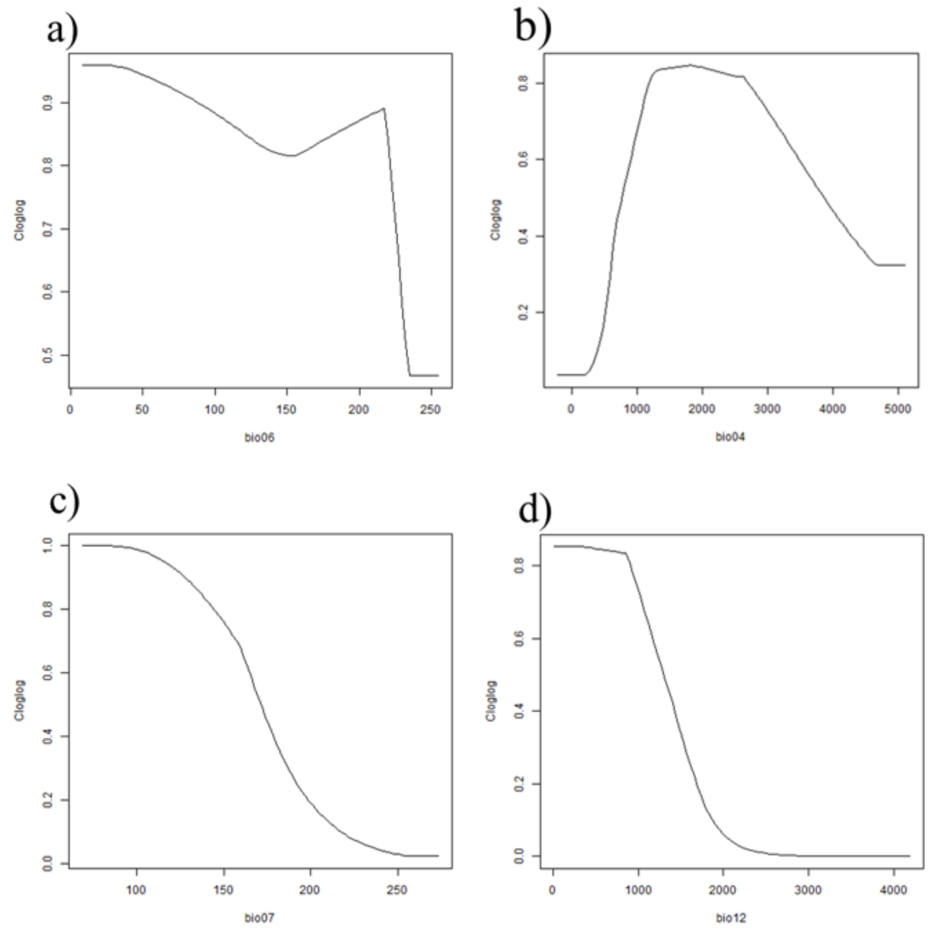


Figure 2. Response curves of the bioclimatic variables. Where: a) minimum temperature in the coldest month (bio6); b) Temperature seasonality response curve (bio4); c) Annual temperature variation response curve (bio7); d) Annual precipitation (bio12) (Source: the author)

Figura 2. Curvas de resposta das variáveis bioclimáticas. Em que: a) temperatura mínima no mês mais frio (bio6); b) sazonalidade da temperatura (bio4); c) variação anual da temperatura (bio7); d) precipitação anual (bio12) (Fonte: o autor)

2.5 Data modeling

We used the R-package wallace (Kass et al., 2018), in which the points of occurrence were included, and the defined climatic variables selected. We used the Area Under the Curve (AUC) (Peterson et al., 2008) and the Akaike Information Criterion (AIC) (Burnham and Anderson, 2002) to select the most suitable model. We chose the best model: LQHP with the Regularization Multiplier equal to 1.0, as shown in Table 4.

Table 4. Model performance statistics (conclusion). Where: L (Linear Model); H (Hinge Model); Q (Quadratic Model); P (Product Model); LQ (Combination of linear and quadratic models); LQH (Combination of linear, quadratic, and hinge models); LQHP (Combination of linear, quadratic, hinge, and product models); RM (Regularization Multiplier); AUC (Area Under the Curve); AIC (Akaike Information Criterion). (Source: the author)

Tabela 4. Estatísticas de desempenho dos modelos (conclusão). Em que: L (Modelo linear); H (Modelo hinge); Q (Modelo quadrático); P (Modelo product); LQ (combinação do modelo linear e quadrático); LQH (combinação dos modelos linear, quadratic e hinge); LQHP (combinação dos modelos linear, quadrático, hinge e product); RM (Multiplicador de Regularização); AUC (Área sob a Curva); AIC (Critério de informação de Akaike). (Fonte: o autor)

Models	RM	AUC	AIC
L	1	0.9454	215.168.836.613.507
L	2	0.9451	215.293.625.957.771
L	3	0.9450	215.380.558.265.096
L	4	0.9450	215.472.351.810.855
L	5	0.9449	215.589.232.851.663
LQ	1	0.9492	212.600.462.668.842
LQ	2	0.9476	213.418.066.756.559
LQ	3	0.9461	214.086.959.419.851
LQ	4	0.9457	214.400.246.265.751
LQ	5	0.9456	214.731.232.156.438
LQH	1	0.9503	212.667.705.929.646
LQH	2	0.9497	212.922.289.542.058
LQH	3	0.9491	21.319.288.112.826
LQH	4	0.9487	213.477.565.714.972
LQH	5	0.9484	213.689.871.229.278
LQHP	1	0.9523	21.228.522.715.042
LQHP	2	0.9508	212.532.361.686.077
LQHP	3	0.9500	212.867.703.460.178
LQHP	4	0.9491	213.214.462.640.068
LQHP	5	0.9484	213.643.607.439.169

In the LQHP model, the value for the 10 Percentile Training Presence was 0.0992. This value refers to the probability of occurrence of 10%, with a threshold function (Costa et al., 2023). During the suitability classification, all areas located in regions classified with values below the threshold were considered unsuitable zones for the occurrence of *C. heliotropiifolius*.

First, a round was calculated for the estimated present occurrence of the species under study. We then made estimates for 2050 and 2070 under pessimistic and optimistic

Revista
ÁRVORE
ISSN 1806 – 9088

climate change scenarios. The coverage area was the territorial limit of Brazil with a buffer of 1 geographical degree.

Once the rounds were completed, maps were generated in TIF format. Using GIS tools, we made a classification of suitability on each map referring to the correlation levels, with values below or equal to the threshold of 0.0992 considered inadequate; between 0.0992 and 0.5 of low suitability; between 0.5 and 0.7 of medium suitability and between 0.7 and the maximum values, of high suitability (Ramos et al., 2019).

After classification, we calculated the areas of each level of suitability for all the scenarios, as well as the difference from the present occurrence area. These calculations were made using the area values shown in the attribute tables of the maps generated. We used square megameters (Mm²) as our measurement unit.

We also obtained mean values for each climate variable. As TIFF files lack attribute tables, we merged the variable files with the plant record points, thus obtaining vector files with attribute tables and climate variable values at each species record point.

3. RESULTS

In the present, the inadequate area calculated was 6.82 Mm². The area of low suitability was 0.97 Mm², whereas the area of medium suitability was 0.33 Mm² and the area of high suitability 0.39 Mm²; totaling a total effective area of occurrence of 1.69 Mm².

In the optimistic scenario for climate change, for the area of low suitability, there was an increase of 171.2% in 2050 and 176.3% in 2070 compared to the present. As for the area of medium suitability, there was an increase of 171.2% in 2050 and 176.3% in 2070 compared to the present. Regarding the area of high suitability, there was a reduction of 8.8% in 2050 and a reduction of 5.8% in 2070 compared to the present. In the high suitability scenario, the areas would practically disappear from the state of Minas Gerais in future periods.

As for the pessimistic scenario, in the area of low suitability there was an increase of 183.8% for 2050 and of 187.6% for 2070. In relation to medium suitability, there was an increase of 121.0% for 2050 and 122.7% for 2070. As for the area of high suitability, there was a reduction of 3.8% in 2050 and an increase of 19.6% for 2070. Once obtained the areas, we calculated the percentage variation in the future scenarios in relation to the values estimated for the present, as shown in Table 5.

Table 5. Values of areas in the present and future, in pessimistic and optimistic scenarios, in square megameters (Mm²), and the variation of the area relative to the present in square megameters and percentage (Source: the author)

Tabela 5. Valores das áreas no presente e no futuro nos cenários pessimistas e otimistas, em megametros quadrados (Mm²) e a variação da área em relação ao presente em megametros quadrados em porcentagem (Fonte: o autor)

Period	Scenario	Suitability	Area (Mm²)	Variation (Mm²)	Variation (%)
Present	-	Inadequate	6.82	-	-
Present	-	Low	0.97	-	-
Present	-	Medium	0.33	-	-
Present	-	High	0.39	-	-
2050	Optimistic	Inadequate	4.44	-2.38	-34.88
2050	Optimistic	Low	2.62	1.66	171.24
2050	Optimistic	Medium	0.73	0.41	123.06
2050	Optimistic	High	0.35	-0.03	-8.80
2050	Pessimistic	Inadequate	4.29	-2.53	-37.15

Cont...

Cont...

Period	Scenario	Suitability	Area (Mm²)	Variation (Mm²)	Variation (%)
2050	Pessimistic	Low	2.74	1.78	183.85
2050	Pessimistic	Medium	0.73	0.40	121.05
2050	Pessimistic	High	0.37	-0.01	-3.77
2070	Optimistic	Inadequate	4.40	-2.42	-35.45
2070	Optimistic	Low	2.67	1.70	176.34
2070	Optimistic	Medium	0.70	0.37	113.14
2070	Optimistic	High	0.36	-0.02	-5.77
2070	Pessimistic	Inadequate	4.10	-2.72	-39.89
2070	Pessimistic	Low	2.78	1.81	187.55
2070	Pessimistic	Medium	0.70	0.37	112.68
2070	Pessimistic	High	0.46	0.08	19.64

We also calculated mean values of the variables in all the scenarios (Table 6). Among the variables with the greatest contribution, the minimum temperature in the coldest month rises in relation to the present in all scenarios. In the pessimistic scenario, it rises from 17°C at present to 18.7°C in 2050 and 19.5°C in 2070. In the optimistic scenario, the increase is smaller, rising from 17°C to 18.1°C in 2050 and 18.2°C in 2070. Temperature seasonality, a variable calculated as the standard deviation of the mean monthly temperature, rises from 13.7°C at present to 14.6°C in 2050 and 15.1°C in 2070 in the pessimistic scenario, while in the optimistic scenario it rises to 14.3°C in 2050, falling to 14°C in 2070. Figures 3 and 4 show the respective maps for the records and expected distributions. Figure 4 shows a clear increase in the area of low suitability in the future scenarios compared to the present, represented by Figure 3.

Table 6. Mean climatic variables. Where: S.T (Seasonality of temperature); T.M.M.F (Minimum temperature in the coldest month); V.A.T (Annual temperature variation); P.A (Annual precipitation); S.P (Seasonality of precipitation); P.T.M.S (Precipitation of the driest quarter); P.T.M.Q (Precipitation of the hottest quarter). (Source: the author)

Tabela 6. Média das variáveis climáticas. Em que: S. T (Sazonalidade da temperatura); T. M. M. F. (Temperatura mínima no mês mais fio); V. A. T (Variação anual de temperatura); P. A. (Precipitação anual); S. P (Sazonalidade da precipitação); P. T. M. S (Precipitação do trimestre mais seco); P. T. M Q (Precipitação do trimestre mais quente). (Fonte: o autor)

Variable	Description	Period	Scenario	Mean value	Measurement unit
bio3	Isothermal	Present	-	7.0	dimensionless
bio3	Isothermal	2050	Optimistic	6.9	dimensionless
bio3	Isothermal	2050	Pessimistic	6.8	dimensionless
bio3	Isothermal	2070	Optimistic	6.9	dimensionless
bio3	Isothermal	2070	Pessimistic	6.7	dimensionless
bio4	S. T	Present	-	13.7	dimensionless
bio4	S. T	2050	Optimistic	14.3	dimensionless
bio4	S. T	2050	Pessimistic	14.6	dimensionless

Cont...

Cont...

Variable	Description	Period	Scenario	Mean value	Measurement unit
bio4	S. T	2070	Optimistic	14.0	dimensionless
bio4	S. T	2070	Pessimistic	15.1	dimensionless
bio6	T. M. M. F.	Present	-	17.0	°C
bio6	T. M. M. F.	2050	Optimistic	18.1	°C
bio6	T. M. M. F.	2050	Pessimistic	18.7	°C
bio6	T. M. M. F.	2070	Optimistic	18.2	°C
bio6	T. M. M. F.	2070	Pessimistic	19.5	°C
bio7	V. A. T	present	-	13.8	°C
bio7	V. A. T	2050	Optimistic	14.2	°C
bio7	V. A. T	2050	Pessimistic	14.4	°C
bio7	V. A. T	2070	Optimistic	14.2	°C
bio7	V. A. T	2070	Pessimistic	14.7	°C
bio12	P. A.	present	-	830.2	mm
bio12	P. A.	2050	Optimistic	778.4	mm
bio12	P. A.	2050	Pessimistic	789.2	mm
bio12	P. A.	2070	Optimistic	765.7	mm
bio12	P. A.	2070	Pessimistic	753.5	mm
bio15	S.P	Present	-	69.8	dimensionless
bio15	S.P	2050	Optimistic	71.1	dimensionless
bio15	S.P	2050	Pessimistic	71.6	dimensionless
bio15	S.P	2070	Optimistic	71.9	dimensionless
bio15	S.P	2070	Pessimistic	73.4	dimensionless
bio17	P. T. M. S	Present	-	60.2	mm
bio17	P. T. M. S	2050	Optimistic	52.7	mm
bio17	P. T. M. S	2050	Pessimistic	52.8	mm
bio17	P. T. M. S	2070	Optimistic	52.0	mm
bio17	P. T. M. S	2070	Pessimistic	49.3	mm
bio18	P. T. M Q	Present	-	194.9	mm
bio18	P. T. M Q	2050	Optimistic	172.1	mm
bio18	P. T. M Q	2050	Pessimistic	173.2	mm
bio18	P. T. M Q	2070	Optimistic	177.3	mm
bio18	P. T. M Q	2070	Pessimistic	157.5	mm

4. DISCUSSION

The first effect of climate change on the distribution of *C. heliotropiifolius* can be seen in the expansion of the area of occurrence with low suitability for the species. The second effect would be the reduction and displacement of highly suitable areas, i.e. distribution centers. These areas have optimal conditions for the species, which according to the Central-Marginal Hypothesis, makes them prone to greater genetic diversity due to the existence of larger and less isolated populations, thus generating greater gene flow (Kitamura et al., 2020). Another important effect is the rise in the minimum temperature in the coldest month in all scenarios and the increase in temperature seasonality, which

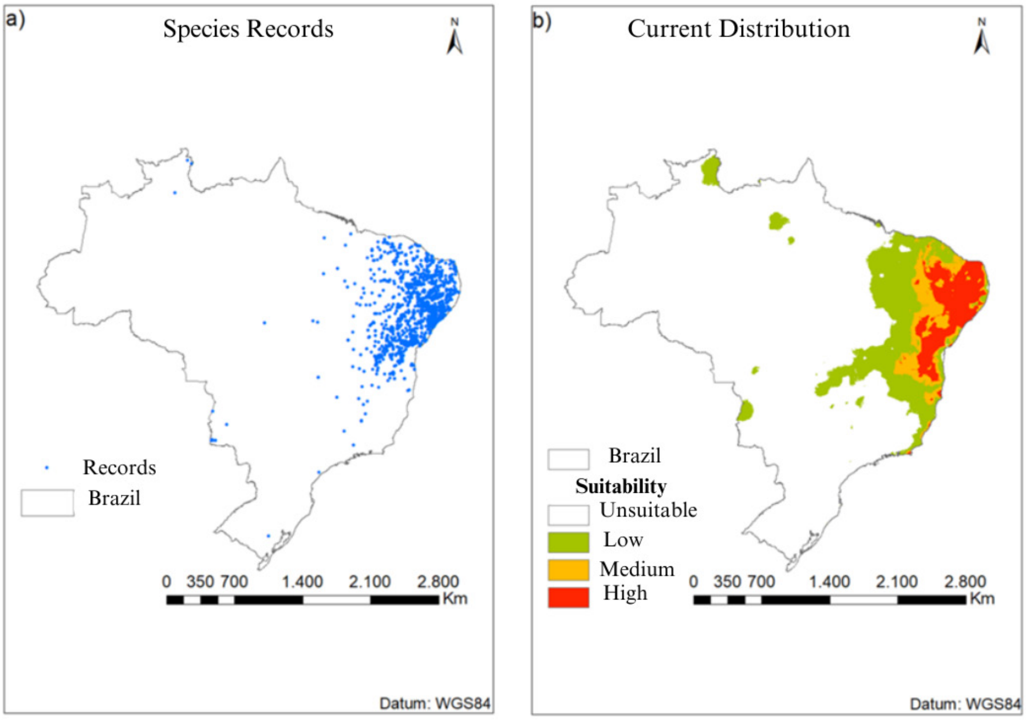
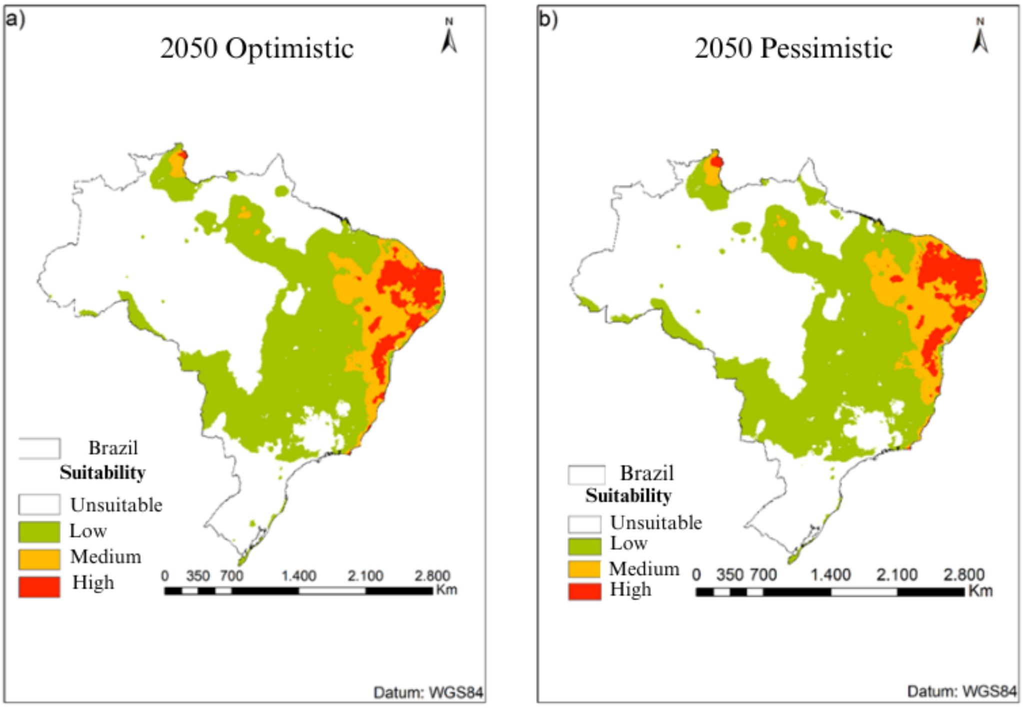


Figure 3. Comparative maps between species records and estimated distribution for the present period. Where: a) map of species records, b) map of estimated distribution for the present (Source: the author)

Figura 3. Mapas comparativos entre os registros da espécie e a distribuição estimada para período presente. Em que: a) mapa dos registros da espécie, b) mapa de distribuição estimada para o presente (Fonte: o autor)



Cont...

Cont...

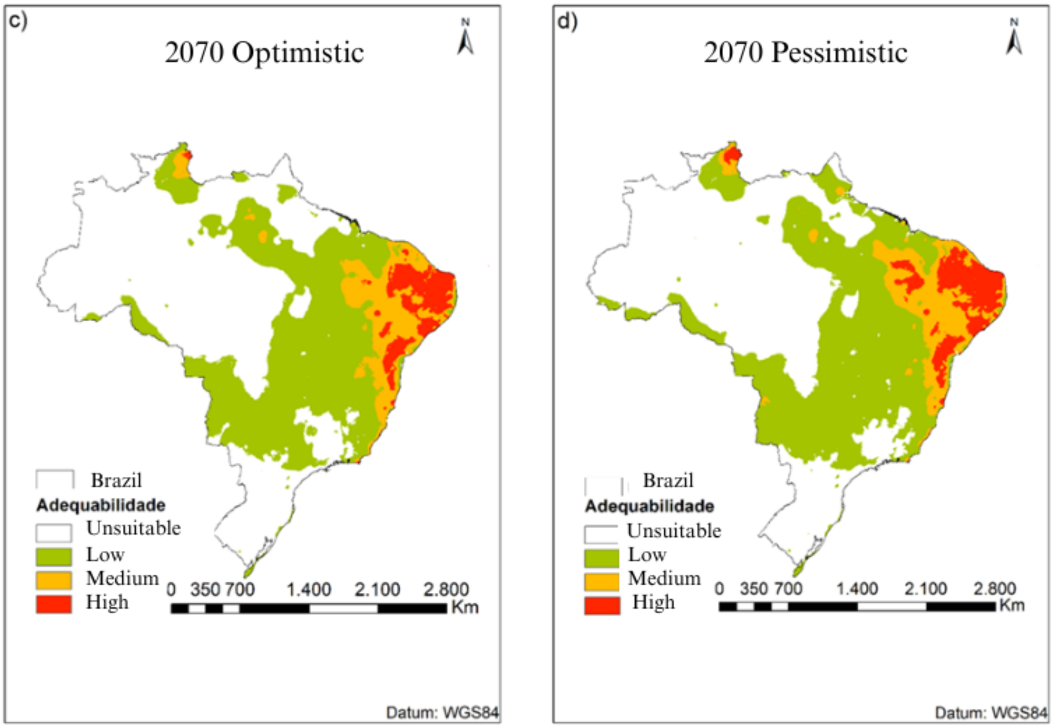


Figure 4. Maps of distribution estimates for future periods. Where: a) map of distribution in 2050 in the optimistic scenario; b) map of distribution in 2050 in the pessimistic scenario; c) map of distribution in 2070 in the optimistic scenario; d) map of distribution in 2070 in the pessimistic scenario (Source: the author)

Figura 4. Mapas da estimativa de distribuição referente aos períodos futuros. Em que: a) mapa da distribuição em 2050 no cenário otimista; b) mapa da distribuição em 2050 no cenário pessimista; c) mapa da distribuição em 2070 no cenário otimista; d) mapa da distribuição em 2050 no cenário pessimista (Fonte: o autor)

showed greater variation in the pessimistic scenario.

Areas of low and medium suitability are considered suboptimal conditions for the species and are usually located on the edges of the distribution. Studies show that marginal populations tend to be smaller and isolated, and consequently more susceptible to genetic erosion due to a lack of cross-fertilization; while populations under optimal conditions have larger populations, and therefore more genetic diversity (Ellstrand and Elam, 1993; Kitamura et al., 2020). In addition, populations in these conditions suffer negative pressures on investment in attractive characteristics, such as flower size and nectar quantity, presenting the so-called self-pollination syndrome (Rech et al., 2018; Tsuchimatsu and Fujii, 2022). According to our results, disturbances culminating in a reduction in areas under optimal conditions would risk isolating currently existing populations, selecting less diverse gene pools, which could result in genetic bottlenecks (Nei et al., 1975).

The decrease in area was only recorded for high suitability in the optimistic scenarios for 2050 and 2070 and in the pessimistic scenario for 2050. Such reduction in habitat could generate a genetic bottleneck effect, reducing the genetic diversity of the species (Nei et al., 1975). However, more data is needed to assess whether the reduction percentages presented are sufficient to generate a genetic bottleneck. Due to the loss of alleles, even small bottleneck effects can generate disadvantages for the population when rapid adaptation to a new environment is required (Nei et al., 1975). Some authors also suggest that when bottleneck effects are strong, speciation might take place (Carson, 1971; Mayr, 1963).

Our modeling also predicted a rise in the minimum temperature in the coldest month, indicating warmer winters. There will also be an increase in temperature seasonality, indicating a greater variation in the range of temperatures during the year. Heat stress caused by climate change can affect plant growth and development, reducing economic yields (Wahid et al., 2007). However, there are still no specific studies investigating the physiological effect of heat stress on *Croton heliotropiifolius*. Studies on the plant's adaptability to such conditions, as well as on preferred terrain and soils, are needed. In addition, it is important to consider that the effects of these changes would not act exclusively on *C. heliotropiifolius*, and there could be a series of other alterations resulting from the predicted changes that would make beekeeping impossible in areas subject to the new climates. However, for better predictions of what might happen in such scenarios, further work must be done, considering other variables or even on-site experiments.

5. CONCLUSION

Our work shows that, based on the bioclimatic envelope, it is possible to predict the environmental suitability of *Croton heliotropiifolius* using MaxEnt and that the climate changes predicted will have an impact on the distribution of the species. Our projections showed that the suitable climatic areas for *C. heliotropiifolius* will cover parts of the northeastern region of Brazil and part of the state of Roraima. Areas of low and medium suitability will expand from today until 2070, indicating that new areas could be included in preservation programs. Reducing areas of high suitability and isolating populations can be detrimental, putting the species at risk of bottleneck effects. We found that the minimum temperature of the coldest month and the temperature seasonality are the most important environmental variables determining the niche of velame. Although we only worked with one species, the results obtained allow us to assume that other plants occurring in the Brazilian semi-arid region may present similar responses to climate change. In addition, future scenarios show a risk of climate change increasing minimum temperature and temperature range in the areas where the species occurs, the consequences of which are uncertain for both velame and other semi-arid species. It is therefore important to develop public policies to mitigate climate change and guarantee the survival of plant species and human quality of life.

6. ACKNOWLEDGEMENTS

Authors acknowledge the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq #400904/2019-5, #423939/2021-1, #311665/2022), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG #APQ-00932-21, #APQ 03100-21, #RED-00039-23, #APQ-02806-22 , #APQ-03364-21, #APQ-01151-22, #APQ-01822-21) and CAPES (#88887.837988/2023-00 and Finantial Code 001) for funding this project.

AUTHOR CONTRIBUTIONS

Conceptualization DRO and ARR, Methodology and Formal analysis DRO, CHSA, TRC, Resources and Funding acquisition ARR, Writing - Original Draft DRO, CHSA and TRC, Writing - Review & Editing DRO, CHSA, ARR and TRC, Supervision TRC and ARR.

7. REFERENCES

Anderson RP, Lew D, Peterson AT. Evaluating predictive models of species' distributions: criteria for selecting optimal models. Ecological Modelling. 2003;162(3):211-232. doi:10.1016/S0304-3800(02)00349-6.

Boria RA, Olson LE, Goodman SM, Anderson RP. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. Ecol Model. 2014;275:73-77. doi:10.1016/j.ecolmodel.2013.12.012.

Burnham KP, Anderson DR. Model selection and multimodel inference: a practical information-theoretic approach. 2nd ed. New York: Springer; 2002. doi: 10.1007/b97636.

Carson HL. Speciation and the founder principle. In: Stadler Genetics Symposium. Columbia, Missouri: University of Missouri; 1971. Available from: https://hdl.handle.net/10355/66544.

Centro de Referência em Informação Ambiental - CRIA. Species Link. 2022. [Accessed em 04/11/2022]. Available at: https://specieslink.net/

Costa TR, da Silva LA, Moura CC, Azevedo CHS, Bueno ML, Mucida DP et al. Vulnerability of the Cerrado–Atlantic Forest ecotone in the Espinhaço Range Biosphere Reserve to climate change. Theor Appl Climatol. 2023;151:1151–1170. doi: 10.1007/s00704-022-04321-z

Delcour I, Spanoghe P, Uyttendaele M. Literature review: Impact of climate change on pesticide use. Food Res. Int. 2015;68:7-15. https://doi.org/10.1016/j.foodres.2014.09.030

de Sousa Vieira LC, de Paula Silva Filho V, Satyamurty, P et al. Simulation of air temperature and their influence on the potential distribution of Myracrodruon urundeuva, Copernicia prunifera and Cereus jamacaru in the Caatinga. SN Appl Sci. 2022;4(26) :1-16. https://doi-org.ez36.periodicos.capes.gov.br/10.1007/s42452-021-04886-w

Ellstrand NC, Elam DR. Population genetic consequences of small population size: implications for Plant Conservation. Annu Rev Ecol Syst. 1993;24:217-242. doi: 10.1146/annurev.es.24.110193.001245.

Fernandes GW, Barbosa NPU, Alberton B, Barbieri A, Dirzo R, Goulart F. The deadly route to collapse and the uncertain fate of Brazilian rupestrian grasslands. Biodivers Conserv. 2018;27:2587–2603. doi: 10.1007/s10531-018-1556-4.

Giannini TC, Siqueira MF, Acosta AL, Barreto FCC, Saraiva AM. Alves-Dos-Santos I. Desafios atuais da modelagem preditiva de distribuição de espécies. Rodriguésia. 2012;63(3):733-749. doi:10.1590/S2175-78602012000300017.

Global Biodiversity Information Facility - GBIF. 2022. [Accessed em 04/11/2022]. Available at: https://www.gbif.org/

Govaerts R, Frodin DG, Radcliffe-Smith A. Croton. In: World Checklist and Bibliography of Euphorbiaceae (and Pandaceae). Kew: Royal Botanic Gardens Kew; 2000. p. 417-536

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. Very high resolution interpolated climate surfaces for global land areas. Int J Climatol. 2005;25(15):1965-1978. doi: 10.1002/joc.1276.

IPCC – Intergovernmental Panel on Climate Change. Synthesis Report: Contribution of working groups I, II, and III to the Fifth Assessment Report. Proceedings of the Intergovernmental Panel on Climate Change. 2014. [cited May 24, 2023]. Available from: https://www.ipcc.ch/report/ar5/syr/.

Intergovernmental Panel on Climate Change – IPCC. AR6 Synthesis Report: Climate Change 2023. 2021. [Accessed: 15/04/2023]. Available from: https://www.ipcc.ch/report/ar6/syr/

Kass JM, Vilela B, Aiello-Lammens ME, Muscarella R, Merow C, Anderson RP. Wallace: A flexible platform for reproducible modeling of species niches and distributions built for community expansion. Methods Ecol Evol. 2018;9:1151–1156. doi: 10.1111/2041-210X.12945.

Kitamura K, Uchiyama K, Ueno S, Ishizuka W, Tsuyama I, Goto S. Geographical Gradients of Genetic Diversity and Differentiation among the Southernmost Marginal Populations of Abies sachalinensis Revealed by EST-SSR Polymorphism. Forests. 2020;11(2):233. doi: 10.3390/f11020233.

Leitão PJ, Moreira F, Osborne PE. Effects of geographical data sampling bias on habitat models of species distributions: a case study with steppe birds in southern Portugal. Int J Geogr Inf Sci. 2011;25(3):439-454. doi:10.1080/13658816.2010.531020.

Matear R, Lenton A. Sensitivity of Future Ocean Acidification to Carbon Climate Feedbacks. Biogeosciences Discuss. 2017;1-18. doi:10.5194/BG-2017-225.

Mayr E. Animal Species and Evolution. In: Belknap Press. Cambridge, MA: Harvard University; 1963.

Nei M, Maruyama T, Chakraborty R. The bottleneck effect and genetic variability in populations. Evolution. 1975;29(1):1-10. doi: 10.1111/j.1558-5646.1975.tb00807.x.

Oliveira BE, da Silva IA, da Silva WF, da Silva JA, da Silva CB, da Silva RR. Investigação fitoquímica e atividade alelopática do extrato foliar da *Croton heliotropiifolius* Kunth sobre o desenvolvimento inicial de Lactuca sativa L. Research, Society and Development. 2022;11(14):e151111435613. doi:10.33448/rsd-v11i14.35613.

Oliveira VS, Nascimento Júnior JM, De Borges RLB, Lima e Lima LC. Floral biology and beekeeping potential of *Croton heliotropiifolius* Kunth (Euphorbiaceae) at semi-arid region, Brazil. Rev. Caatinga. 2021;34(4).

Peterson AT, Papeş M, Soberón J. Rethinking receiver operating characteristic analysis applications in ecological niche modeling. Ecol Modell. 2008;213(1):63-72. doi: 10.1016/j.ecolmodel.2007.11.008.

Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modeling of species geographic distributions. Ecol Modell. 2006;190:231-259. doi: 10.1016/j.ecolmodel.2005.03.026.

Ramos RS, Kumar L, Shabani F, Picanço MC. Risk of spread of tomato yellow leaf curl virus (TYLCV) in tomato crops under various climate change scenarios. Agricultural Systems. 2019;173:524:535. doi:10.1016/j.agsy.2019.03.020

Rech AR, Jorge LR, Ollerton J, Sazima M. Pollinator availability, mating system and variation in flower morphology in a tropical savanna tree. Acta Bot Bras. 2018;32(3):462-472. doi: 10.1590/0102-33062018abb0220.

Santos, AS. Biologia reprodutiva e citogenética de espécies simpátricas de Croton l. (Euphorbiaceae). Repositório UFPB, 2016. [Accessed: 21/07/2024]. Available at: https://repositorio.ufpb.br/jspui/handle/123456789/15473

Silva LS, Costa, TR, Teixeira RS. Modelagem preditiva de Vellozia cinerascens (Mart.) Mart. ex Seub: Mudanças Climáticas poderão afetar sua ocorrência? Diversitas Journal. 2022;7(4):2331 – 2342. doi:10.48017/dj.v7i4.2013.

Silva JS, Sales MF, Gomes APS, Carneiro-Torres DS. Sinopse das espécies de Croton L. (Euphorbiaceae) no estado de Pernambuco, Brasil. Acta Bot Bras. 2010;24(2):441-453

Steffen W, Richardson K, Rockström J, et al. Planetary boundaries: Guiding human development on a changing planet. Science. 2015;347:1259855. https://doi.org/10.1126/science.1259855

Sousa JM, Souza EL, Marques G, Meireles B, Cordeiro ATM, Gullón B, et al. Polyphenolic profile and antioxidant and antibacterial activities of monofloral honeys produced by Meliponini in the Brazilian semiarid region. Food Research International. 2016;84:61-68. doi:10.1016/j.foodres.2016.03.012.

Superintendência do Desenvolvimento do Nordeste - SUDENE. Delimitação do semiárido. 2021. [Accessed: 11/01/2024]. Available at: https://www.gov.br/sudene/pt-br/centrais-de-conteudo/02semiaridorelatorionv.pdf

Tavares VC, Arruda IRP, Silva DG. Desertificação, mudanças climáticas e secas no semiárido brasileiro: uma revisão bibliográfica. Geosul. 2019;34(70):385-405. doi:10.5007/2177-5230.2019v34n70p385.

Tsuchimatsu T, Fujii S. The selfing syndrome and beyond: diverse evolutionary consequences of mating system transitions in plants. Philos Trans R Soc Lond B Biol Sci. 2022;377:1855. doi:10.1098/rstb.2020.0510

Wahid A, Gelani S, Ashraf M, Foolad MR. Heat tolerance in plants: An overview. Environ Exp Bot. 2007;61(3):199-223. doi:10.1016/j.envexpbot.2007.05.011