Research Article

Future projections and ecological modeling for the distribution of non-conventional food plants[1]

Carla Karoline Gomes Dutra Borges[2], Jennifer Souza Tomaz[2],
Caroline de Souza Bezerra[2], Marcos Silveira Wrege[3], Maria Teresa Gomes Lopes[2]

ABSTRACT

The importance of non-conventional food plants has been evidenced due to their great potential for phenotypic plasticity, resilience and resistance to permanence in inhospitable places. This study aimed to evaluate the natural distribution of two of these species (*Eryngium foetidum* and *Fridericia chica*) in the present period (2009-2019) and the projection for two future climate scenarios (RCP 4.5 - "less pessimistic" and RCP 8.5 - "more pessimistic") in two-time intervals (2020-2050 and 2051-2070), in the six Brazilian phytogeographic domains. Nineteen bioclimatic variables obtained from the WorldClim database and four algorithm models were tested: Climate Space Model, Envelope Score, Niche Mosaic and Environmental Distance. The Environmental Distance algorithm presented the best discrimination of the models adjusted for the two species. From the projections, it is possible to perceive that the species are severely affected in the phytogeographic domains of the Amazon, Pantanal and Pampa, becoming practically extinct in the RCP 8.5 scenario, for the period of 2051-2070.

KEYWORDS: *Eryngium foetidum* L., *Fridericia chica* (Bonpl.) L. G. Lohmann, climate projection.

RESUMO

Projeções futuras e modelagem ecológica para a distribuição de plantas alimentícias não convencionais

A importância de plantas alimentícias não convencionais tem sido evidenciada devido ao seu grande potencial de plasticidade fenotípica, resiliência e resistência à permanência em lugares inóspitos. Objetivou-se estudar a distribuição natural de duas espécies dessas plantas (*Eryngium foetidum* e *Fridericia chica*) no período presente (2009-2019) e a sua projeção para dois cenários climáticos futuros (RCP 4.5 - "menos pessimista" e RCP 8.5 - "mais pessimista") em dois intervalos de tempo (2020-2050 e 2051-2070), nos seis domínios fitogeográficos brasileiros. Foram utilizadas 19 variáveis bioclimáticas obtidas da base de dados do WorldClim e quatro modelos de algoritmos foram testados: Climate Space Model, Envelope Score, Niche Mosaic e Environmental Distance. O algoritmo Environmental Distance apresentou a melhor discriminação dos modelos ajustados para as duas espécies. A partir das projeções, é possível perceber que as espécies são severamente afetadas nos domínios fitogeográficos da Amazônia, Pantanal e Pampa, tornando-se praticamente extintas no cenário RCP 8.5 para o período de 2051-2070.

PALAVRAS-CHAVE: *Eryngium foetidum* L., *Fridericia chica* (Bonpl.) L. G. Lohmann, projeção climática.

INTRODUCTION

Approximately 390,000 plant species are known worldwide (Tuler et al. 2019). However, only one thousand are used for human feeding (FAO 2018, Tuler et al. 2019). As for Brazil, its biodiversity of plant species corresponds to more than 10 % of the world's total, comprising 46,097 native species, of which 4 to 5 thousand can be part of food consumption (Terra & Ferreira 2020).

However, this natural richness and its potential for food use are still little known, since, in Brazil, there is a preference for the consumption of arable species, since the diet of Brazilians includes mainly rice, coffee and bean (Silva et al. 2017, Tuler et al. 2019, Terra & Ferreira 2020). In this condition, the concept of non-conventional food plants emerges, since they are plants that are totally or partially edible, but are generally not included in the usual food consumption of the population and are often considered weeds, because they grow spontaneously in various environments (Liberato et al. 2019, Terra & Ferreira 2020, Silva et al. 2022).

[1] Received: May 29, 2023. Accepted: Sep. 29, 2023. Published: Nov. 03, 2023. DOI: 10.1590/1983-40632023v5376279.
[2] Universidade Federal do Amazonas, Manaus, AM, Brazil. *E-mail/ORCID*: carlaborges.am@gmail.com/0000-0001-8844-4527; jennifertomaz14@gmail.com/0000-0001-6612-2172; caroline_souza16@hotmail.com/0000-0002-0380-4181; mtglopes@hotmail.com/0000-0003-1988-7126.
[3] Empresa Brasileira de Pesquisa Agropecuária (Embrapa Florestas), Curitiba, PR, Brazil. *E-mail/ORCID*: marcos.wrege@gmail.com/0000-0002-6368-6586.

Non-conventional food plants have a high genetic variability and rusticity, so they can be maintained and managed according to the soil and climate conditions to which they are adapted (Kelen et al. 2015, Terra & Ferreira 2020). These species can represent an extra source of income for small farmers, contributing directly to the local and regional economy, since they can be grown without many difficulties. In addition, the Brazilian diet may vary (Biondo & Zanetti 2018).

Currently, many unconventional species have had their food and medicinal potential emphasized. Among them is *Eryngium foetidum* L., which has a wide distribution in the Brazilian territory, with a phytogeographic domain in the Amazon (Kinupp & Lorenzi 2019, Rodrigues et al. 2022). Popularly known as "chicória", "chicória-do-Pará", "coentrão" or "chicória da Amazônia", it is considered an unconventional vegetable seasoning that has aroused the interest of researchers, since it presents a high versatility as an herbal plant and spice, besides increasing popularity, being among the main cultivated non-conventional vegetables (Thomas et al. 2017, Leitão et al. 2020, Rosero-Gómez et al. 2020, Rodrigues et al. 2022).

Fridericia chica (Bonpl.) L. G. Lohmann also stands out, which has a wide distribution in Brazil and confirmed occurrence in all Brazilian regions and phytogeographic domains (Lohmann 2015, Batalha et al. 2022). It is popularly known as "crajiru", "carajiru", "chica" and "cipó-cruz", among others (Lorenzi et al. 2002, Lohmann 2015, Batalha et al. 2022). Its leaves are used as tea and have anti-inflammatory, antioxidant, antidiabetic and disinfectant activity (Oliveira et al. 2009, Batalha et al. 2022).

Anthropogenic actions that lead to the reduction of plant areas put the floristic biological diversity and food sovereignty at risk, what is closely related to the consumption of non-conventional food plants. Therefore, it is crucial to conduct studies that predict the scenarios of the occurrence zones of these species in the upcoming decades to assist in conservation and research (Sousa et al. 2020). Climate change, being one of the main factors that contribute to the loss of biodiversity (Aleixo et al. 2010), may cause the reduction of the distribution of species, genetic variability and increase in endogamous mating (Tomaz et al. 2022). However, some species exhibit phenotypic plasticity and can adapt well to new environmental conditions (Aitken et al. 2008).

The issue of global climate change has gained worldwide attention, both politically and scientifically. Its negative impact on human quality of life and the entire planet was evident in the Sixth Climate Change Assessment Report (AR6) prepared by the Intergovernmental Panel on Climate Change in 2021 (IPCC 2021). Climate change causes changes in weather patterns, which have severe impacts on all continents and oceans. In recent decades, there has been a significant increase in natural disasters such as floods, droughts, forest fires, cyclones and storms, amongst others. These changes are highlighted by several studies, including Reis et al. (2017) and Silva & Behr (2021).

Studies also have shown that climate change can be demonstrated through modeling, particularly over an extended period (Almeida & Cavalcante 2020). One of the most recommended methodologies for studying ecology, evolution, conservation and genetic breeding is the Ecological Niche Modeling. This methodology enables researchers to correlate the distribution of a species with environmental variables, which, in turn, allow them to identify the best conditions for the occurrence of the species and determine the impact of climate change on it. This information is useful in defining measures for the conservation of species (Wrege et al. 2017, Tourne et al. 2019, Sousa et al. 2020).

Thus, this study aimed to model the potential distribution of *E. foetidum* and *F. chica* under current and future climate scenarios using the Ecological Niche Modeling.

MATERIAL AND METHODS

The geographical coordinates information for consistent occurrences of *Eryngium foetidum* and *Fridericia chica* were obtained from open access databases such as the Reference Center for Environmental Information (CRIA 2022), the SpeciesLink platform (CRIA 2022) and the Global Biodiversity Information Facility (GBIF 2022) in 2022, at the Universidade Federal do Amazonas, in Manaus, Amazonas state, Brazil. All data were limited to Brazilian phytogeographic domains and were processed using the geographic information system (GIS) in the ArcMap software (Esri 2011). The occurrences of the species were analyzed using the tidyverse package (Wickham 2017, RStudio 2022), which helped in removing duplicates, incorrect and missing coordinates, as well as occurrences that did not have location data.

A total of 19 bioclimatic variables, obtained from the WorldClim project dataset, version 2.1 (Fick & Hijmans 2017), were used. These variables are derived from monthly values of air temperature (minimum and maximum; in ºC) and rainfall (mm) (Wrege et al. 2017, Rebello et al. 2023). The spatial resolution of the layers was 2.5 arc-minutes, which is equivalent to an area of approximately 5 km² (Rebello et al. 2023). The data were processed using the R Development Core Team (2022) and its RStudio Team add-on (2022).

Out of the 19 principal components, it was discovered that six were responsible for most of the variation. These six components were used in the species modeling process and accounted for 97.8 % of the first PCA eigenvectors. The six components are: Bio4 (temperature seasonality - standard deviation multiplied by 100); Bio6 (minimum temperature in the coldest month); Bio9 (average temperature in the driest quarter); Bio13 (accumulated rainfall in the wettest month, measured in mm); Bio14 (accumulated rainfall in the driest month); and Bio17 (rainfall accumulated in the driest quarter, measured in mm).

The potential distribution of species was obtained by multiple linear regression, so that the bioclimatic variables were related to the numerical models of latitude, longitude and altitude (Gomes et al. 2022). The scenarios were obtained from general circulation models (GCM) available at the Data Distribution Centre of the sixth Evaluation Report of the Intergovernmental Panel on Climate Change (IPCC 2021). Three atmospheric circulation models were selected: HadGEM-GC31-LL, IPSL-CM6Ä-LR (Firpo et al. 2022) and MIROC6 (Monteverde et al. 2022), two of which were averaged to increase the model accuracy (Dormann et al. 2018).

According to the obtained data, the present period (2009-2019) and future projections (2020-2050 and 2051-2070) were considered, with two climate scenarios [“less pessimistic” (RCP 4.5) and “more pessimistic” (RCP 8.5)] for the emission of greenhouse gases, whereas, for the RCP 8.5, strategies that reduce the greenhouse effect were not considered (Li et al. 2020, Gomes et al. 2022, Tomaz et al. 2022), in addition to considering the six Brazilian phytogeographic domains (Amazon, Caatinga, Cerrado, Pantanal, Atlantic Forest and Pampa).

The Climate Space Model, Envelope Score, Niche Mosaic and Environmental Distance algorithms were used to predict the species distribution with a higher accuracy. To determine the best-performing model, the area under the curve (AUC) metric was evaluated by integrating the Receiver Operating Characteristic (ROC) analysis (Allouche et al. 2006). The AUC ranges between 0 and 1 (Fielding & Bell 1997), and the Environmental Distance model was found to have the best distribution for both species, as it showed an AUC value of 1.0, indicating a perfect discrimination.

The maps generated by OpenModeller software were saved in the American Standard Code for Information Interchange (ASCII) format and contained binary values. These maps were transformed to the “raster” format according to the Esri (2011) protocol. The categories were established on a gradient scale from 0 to 1, where 0 represented areas without the possibility of occurrence, and 1 indicated areas with the maximum possibility of occurrence (Muñoz et al. 2011, Gomes et al. 2022).

RESULTS AND DISCUSSION

After the data passed through the cleaning procedure, a final occurrence matrix was obtained, with 352 single points of occurrence of *Eryngium foetidum* in South America, sufficient for the modeling study of the species. Figure 1 shows the distribution of the species by the points of occurrence in the Brazilian territory.

The correspondence-based distribution model of the species for the current period indicates its climatic suitability. The species is distributed across six Brazilian phytogeographic domains, with the Amazon region having the highest occurrence (Figure 2A). The *Eryngium* genus is cosmopolitan and South America is believed to be the center of its species diversity (Acharya et al. 2022). Therefore, the Environmental Distance algorithm’s distribution prediction aligns with the distribution patterns described in the literature (Kinupp & Lorenzi 2019, Rodrigues et al. 2022).

The projections for the future, based on the RCP 4.5 (Figures 2B and 2C) and RCP 8.5 (Figures 3B and 3C) scenarios, indicate that there will be a decrease in areas suitable for the growth

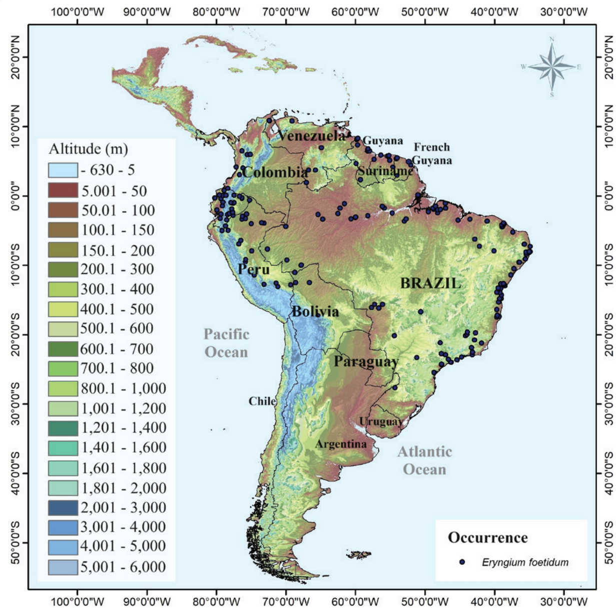

Figure 1. Occurrence data of *Eryngium foetidum* in South America.

of *E. foetidum* in all the Brazilian phytogeographic regions during the 2020-2050 and 2051-2070 periods. This highlights the susceptibility of the species to the impacts of climate change.

In the RCP 4.5 scenario for the 2020-2050 period, it was possible to verify a significant reduction in areas of climate adaptation for the species, especially in the Amazon, Pampa and Pantanal domains, indicating a region of greater vulnerability to climate change. On the other hand, it is possible to verify that, although in a smaller proportion of the area, the individuals present in the Caatinga, Cerrado and the coastal part of the Atlantic Forest presented areas of climatic adequacy for the occurrence of the species (Figure 2B).

For the 2051-2070 period, it was observed that, in addition to the Pantanal and Pampa domains, the Amazon presents more significant losses of areas favorable to the distribution of the species, and that the Caatinga and the coastal part of the Atlantic Forest tend to provide areas of climatic adaptation for *E. foetidum* (Figure 2C).

Climatic factors such as temperature and luminosity directly affect the growth and development of unconventional vegetables, especially those with a short cycle, such as *E. foetidum* (Hirata & Hirata 2015, Gomes et al. 2023). In the Amazon phytogeographic domain, there will be a loss of suitable area for the species, suggesting that climate change will reduce the occurrence of *E. foetidum* in its native region. In areas of the Cerrado, even with the increase in temperature in a future scenario (Ferreira et al. 2022), there will be environmental adequacy for the species. However, it is possible to observe little empirical support in the relation climatic adequacy and plant performance (Sporbert et al. 2022), which suggests that climatic adequacy does not guarantee its occurrence. Thus, understanding how climate change affects plant performance is of fundamental importance to verify the response of these species to climate change and to draw conservation strategies (Sutherland et al. 2013).

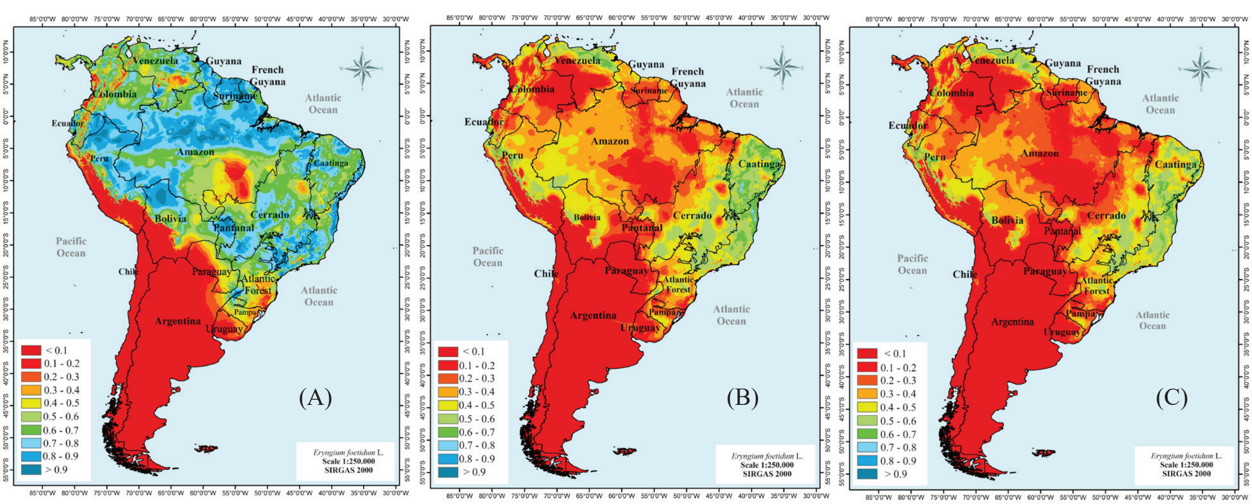

Figure 2. Projection for 2009-2019, in the current period (A), and 2020-2050 (B) and 2051-2070 (C), in the "less pessimistic" scenario (RCP 4.5), of *Eryngium foetidum* in the Brazilian phytogeographic domains, according to global climate change.

According to the RCP 8.5 scenario, there will be a significant decline in the occurrence of species in the Amazon phytogeographic domain from 2020 to 2050 (Figure 3B), when compared to the current period (Figure 3A). In the following period, from 2051 to 2070, it will decrease in almost all the six Brazilian phytogeographic domains (Figure 3C).

In the northeastern part of the Amazon, under high emissions, the RCP 8.5 scenario indicates a significant increase in areas vulnerable to forest fires during the 2020-2040 and 2080-2100 periods. This could adversely affect biodiversity and ecosystems on a local scale (Santana et al. 2022). In the southern Amazon, it is predicted that 16 % of the region's forests will be affected by climate change by 2050, primarily due to areas susceptible to forest fires (Brando et al. 2020).

Based on the evaluation of the RCP 4.5 and RCP 8.5 scenarios, there has been a reduction of areas suitable for the growth and development of *E. foetidum* during the studied periods (Figures 4 and 5). The Amazon and Pantanal domains are highly sensitive to variations in climate, making them the most vulnerable to the ongoing climate change (Marengo & Souza Júnior 2018). Conversely, the Pampa phytogeographic domain has exhibited limited areas suitable for *E. foetidum* in all the studied scenarios, due to the intense agricultural activities in that region (Suzuki et al. 2019).

After the removal of outliers, 186 georeferencing points were obtained in South America for the *F. chica* species (Figure 6).

The species comprises all the Brazilian phytogeographic domains and may occur from

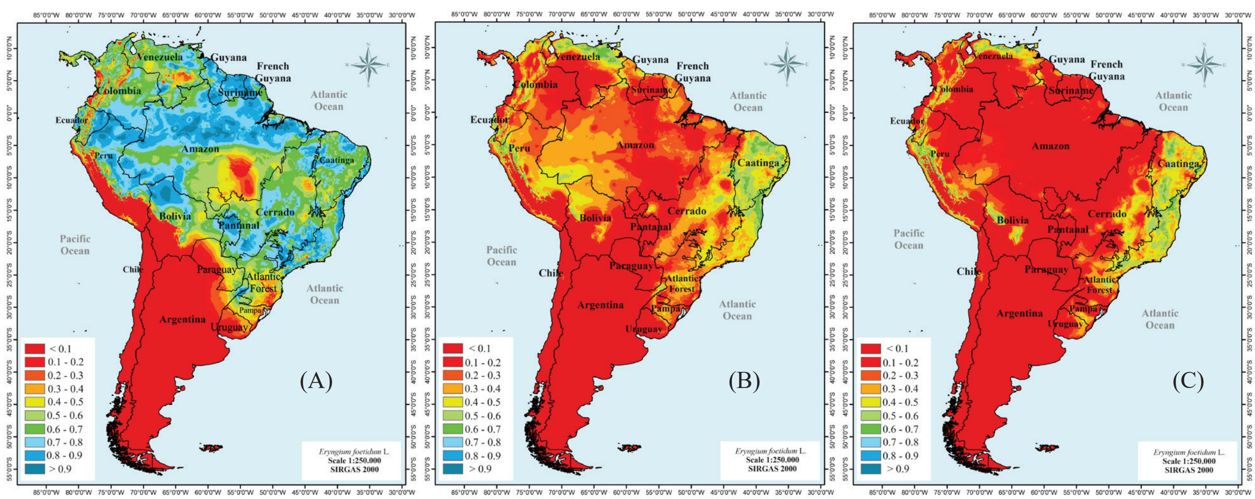

Figure 3. Projection for 2009-2019, in the current period (A), and 2020-2050 (B) and 2051-2070 (C), in the "more pessimistic" scenario (RCP 8.5), of *Eryngium foetidum* in the Brazilian phytogeographic domains, according to global climate change.

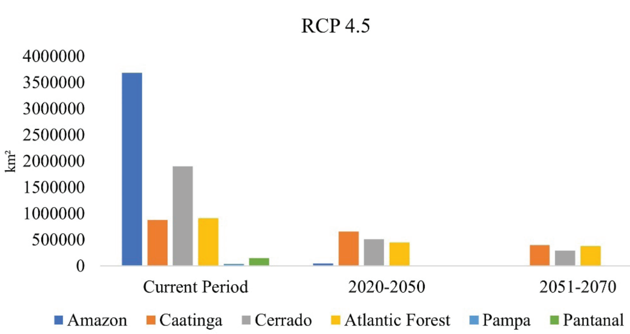

Figure 4. Projection of distribution area (in km²) by phytogeographic domain of *Eryngium foetidum* in the "less pessimistic" scenario (RCP 4.5), for the current (2009-2019) and future (2020-2050 and 2051-2070) periods.

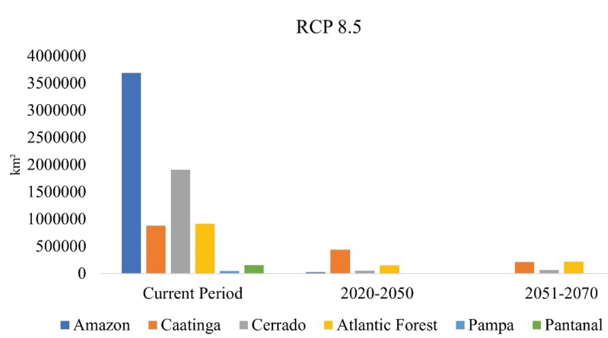

Figure 5. Projection of distribution area (in km²) by phytogeographic domain of *Eryngium foetidum* in the "more pessimistic" scenario (RCP 8.5), for the current (2009-2019) and future (2020-2050 and 2051-2070) periods.

the Amazon to the extreme south of the country (Figure 7A). Thus, it is possible to characterize it as a resilient species that presents survival mechanisms, since it occurs in different environments (Brito et al. 2015, Batalha et al. 2022).

For the RCP 4.5 scenario, in the 2020-2050 (Figure 7B) and 2051-2070 (Figure 7C) periods, it was observed that the Amazon, Cerrado and Pantanal domains are the most vulnerable to climate change.

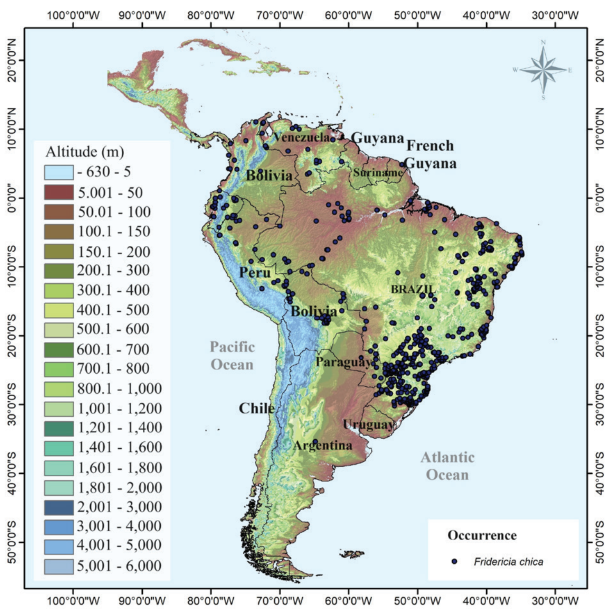

Figure 6. Points of occurrence of *Fridericia chica* in Brazil and South America.

However, due to its extension and for being the distribution center of the species, the Amazon domain is the most susceptible to the loss of suitable area (Figure 7).

Fridericia chica has a large-scale distribution in the Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampa domains, with predominance in the Amazon, corroborating studies such as Batalha et al. (2022), which states that the species has a common occurrence in the Amazon region, being an autochthonous species that develops in tropical forests and stands out in secondary forests, that is, adapts easily to hostile environments.

According to the future projections made for the RCP 8.5 scenario for the 2020-2050 (Figure 8B) and 2051-2070 (Figure 8C) periods, there will be a considerable area reduction in all the Brazilian phytogeographic domains suitable for the occurrence of the species (Figure 8).

The analysis of future scenarios shows that there will be a reduction in areas suitable for the presence of *F. chica* during the 2020-2050 and 2051-2070 periods (Figures 9 and 10). As a result, the Amazon, Pampa and Pantanal domains will be the most affected.

Anthropogenic and economic activities such as urbanization, agriculture and agricultural expansion directly affect the Amazon vegetation cover, generating impacts on the climate at scales that can reach global levels (Mertens et al. 2002, Ometto et al. 2011, Arraut et al. 2012). In addition,

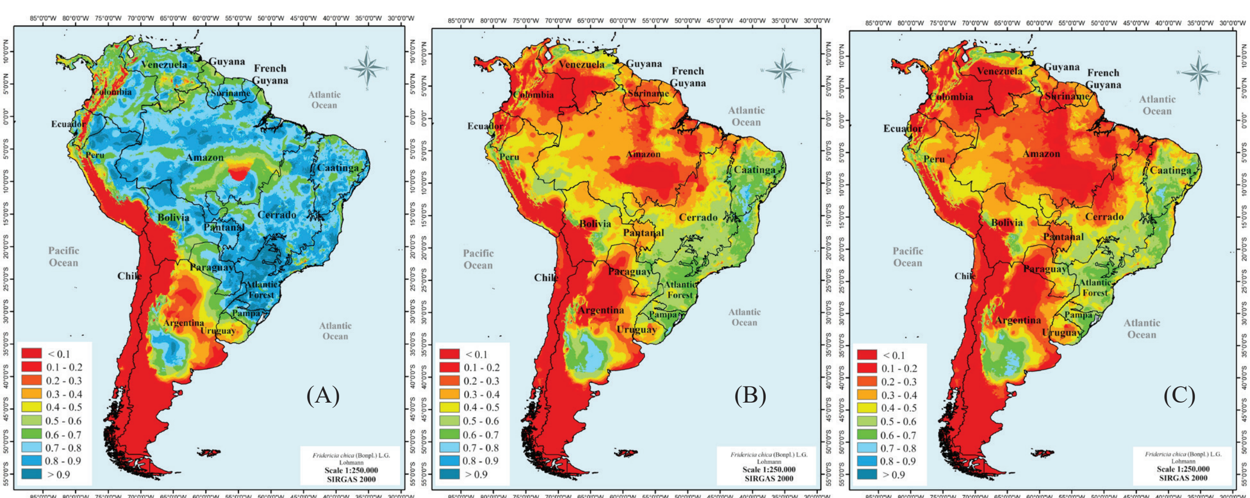

Figure 7. Projection for 2009-2019, in the current period (A), and 2020-2050 (B) and 2051-2070 (C), in the "less pessimistic" scenario (RCP 4.5), of *Fridericia chica* in the Brazilian phytogeographic domains, according to global climate change.

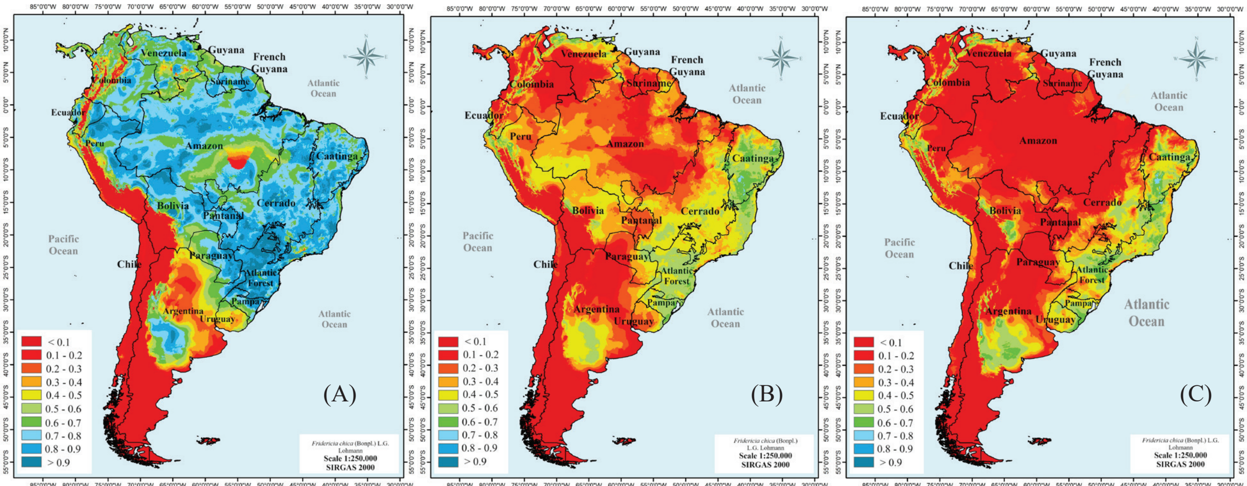

Figure 8. Projection for 2009-2019, in the current period (A), and 2020-2050 (B) and 2051-2070 (C), in the "more pessimistic" scenario (RCP 8.5), of *Fridericia chica* in the Brazilian phytogeographic domains, according to global climate change.

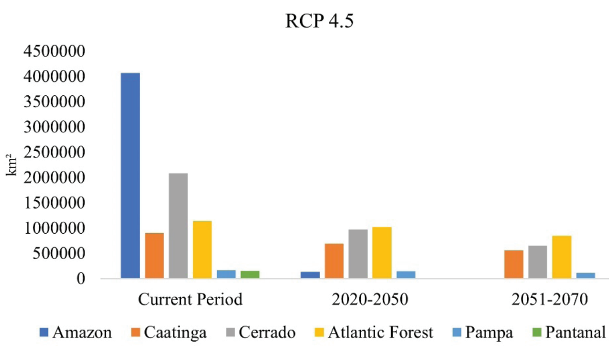

Figure 9. Projection of distribution area (in km²) by phytogeographic domain of *Fridericia chica* in the "less pessimistic" scenario (RCP 4.5), for the current (2009-2019) and future (2020-2050 and 2051-2070) periods.

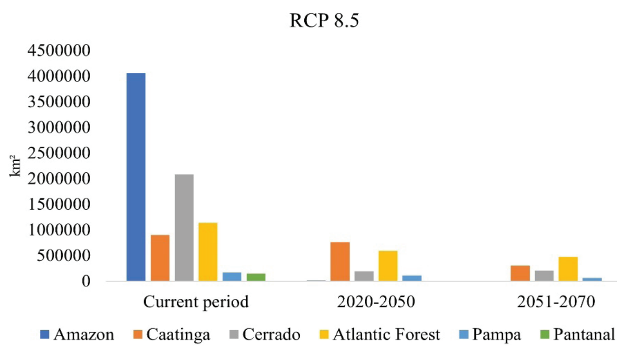

Figure 10. Projection of distribution area (in km²) by phytogeographic domain of *Fridericia chica* in the "more pessimistic" scenario (RCP 8.5), for the current (2009-2019) and future (2020-2050 and 2051-2070) periods.

climate change scenarios for this domain, designed by climate models obtained through the IPCC report (IPCC 2021), show an increase in the average air temperature until the end of the 21st Century above 4 ºC and a reduction in rainfall by up to 40 % (IPCC 2021).

The Amazon phytogeographic domain is currently facing a significant risk due to extreme climate variations predicted for the region. However, the risk is not just limited to climate change, but also to the existing synergistic interactions with other threats, such as deforestation, forest fragmentation and fires, since deforestation poses an immediate threat to the Amazon rainforest, while climate change is a more long-term threat (Marengo & Souza Júnior 2018).

The Pampa and Pantanal domains, just like the Amazon, are extremely delicate, due to the fast growth of agriculture and expansion (Fausto et al. 2016). The Pantanal area is especially vulnerable to deforestation, because of the increased demand for pastures and the cultivation of crops such as soybean and corn, which require large areas of cleared land for planting (Azevedo & Saito 2013, Fausto et al. 2016).

As for the Pantanal, it is considered the most extensive tropical flood area in the world, and, between October and December 2019, it had the highest number of fires in the last 17 years (Brasil 2020). It is considered one of the most essential phytogeographic domains in Brazil. It presents microclimatic changes in the transformation of forests into pasture areas, directly affecting the temperature (Biudes et al. 2012) and, consequently, the species that occur there.

Ecological and evolutionary history can determine the suitable area for a species according to literature data (Barve et al. 2011). Factors that determine these areas include tolerance limits, the needs of the species, interaction with other species and its potential for dispersal (Cabral & Schurr 2010). These factors are affected by the locations of rivers, climate, rock formations and other barriers which may change over time (Soberón 2010). The species can respond to physical and biotic environments in different ways, and its ecological niches can remain stable or evolve (Vanderwal et al. 2009). This may explain the behavior of the species when comparing the base period with future scenarios.

Due to the significance of the *E. foetidum* and *F. chica* species for small farmers and the regional economy, it is highly recommended to conduct sampling and seed collections of their populations in the Amazon. Moreover, it is crucial to prioritize this region for the implantation of new plantings and development of germplasm collections. This approach will help in conducting research on plant breeding, genetic variability, conservation and potential for adaptation and regeneration of these species.

CONCLUSION

The occurrence areas of *Eryngium foetidum* and *Fridericia chica* are severely affected by global climate change, especially by temperature and rainfall, in the Brazilian phytogeographic domains of the Amazon, Pantanal and Pampa. In the Amazon, the species can become extinct, in the "more pessimistic" scenario, by 2070.

ACKNOWLEDGMENTS

This research was financially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes). We thank the Fundação de Amparo a Pesquisa do Estado do Amazonas (FAPEAM) for the scholarship to the first author.

REFERENCES

ACHARYA, G. A.; MOHANTY, S.; DASGUPTA, M.; SAHU, S.; SINGH, S.; KOUDINYA, A. V. V.; KUMARI, M.; NARESH, P.; SAHOO, M. R. Molecular phylogeny, DNA barcoding, and ITS2 secondary structure predictions in the medicinally important *Eryngium* genotypes of east coast region of India. *Genes*, v. 13, n. 9, e1678, 2022.

AITKEN, S. N.; YEAMAN, S.; HOLLIDAY, J. A.; WANG, T. L.; CURTIS-MCLANE, S. Adaptation, migration or extirpation: climate change outcomes for tree populations. *Evolutionary Applications*, v. 1, n. 1, p. 95-111, 2008.

ALEIXO, A. L. P.; ALBERNAZ, A. L. K. M.; GRELLE, C. E. V.; VALE, M. M.; RANGEL, T. F. Mudanças climáticas e a biodiversidade dos biomas brasileiros: passado, presente e futuro. *Natureza & Conservação*, v. 8, n. 2, p. 194-196, 2010.

ALLOUCHE, O.; TSOAR, A.; KADMON, R. Assessing the accuracy of species distribution models: prevalence, kappa, and the true skill statistic (TSS). *Journal of Applied Ecology*, v. 43, n. 6, p. 1223-1232, 2006.

ALMEIDA, R. G.; CAVALCANTE, A. M. B. Impactos das mudanças climáticas no bioma Caatinga na percepção dos professores da rede pública municipal de General Sampaio - Ceará. *Revista Brasileira de Meteorologia*, v. 35, n. 3, p. 397-405, 2020.

ARRAUT, J. M.; NOBRE, C.; BARBOSA, H. M. J.; OBREGON, G.; MARENGO, J. Aerial rivers and lakes: looking at large-scale moisture transport and its relation to Amazonia and to subtropical rainfall in South America. *Journal of Climate*, v. 25, n. 2, p. 543-556, 2012.

AZEVEDO, A. A.; SAITO, C. H. Deforestations profile in Mato Grosso, after implementation of the environmental licensing in rural properties. *Cerne*, v. 19, n. 1, p. 111-122, 2013.

BARVE, N.; BARVE, V.; JIMÉNEZ-VALVERDE, A.; LIRA-NORIEGA, A.; MAHER, S. P.; PETERSON, A. T.; SOBERÓN, J.; VILLALOBOS, F. The crucial role of the accessible area in ecological niche modeling and species distribution modeling. *Ecological Modelling*, v. 222, n. 11, p. 1810-1819, 2011.

BATALHA, A. D. S. J.; SOUZA, D. C. M.; UBIERA, R. D.; CHAVES, F. C. M.; MONTEIRO, W. M.; SILVA, F. M. A. da; KOOLEN, H. H. F.; BOECHAT, A. L.; SARTIM, M. A. Therapeutic potential of leaves from *Fridericia chica* (Bonpl.) L. G. Lohmann: botanical aspects, phytochemical and biological, anti-inflammatory, antioxidant and healing action. *Biomolecules*, v. 12, n. 9, e1208, 2022.

BIONDO, E.; ZANETTI, C. Diversidade e potencial de utilização de plantas alimentícias não convencionais ocorrentes no vale do Taquari, RS. *Revista Eletrônica Científica*, v. 4, n. 1, p. 61-90, 2018.

BIUDES, M. S.; NOGUEIRA, J. D. S.; DALMAGRO, H. J.; MACHADO, N. G.; DANELICHEN, V. H. M.; SOUZA, M. C. Change in microclimate caused by conversion of a Cambará forest to pasture in the northern Pantanal. *Revista de Ciências Agro-Ambientais*, v. 10, n. 1, p. 61-68, 2012.

BRANDO, P. M.; SOARES-FILHO, B.; RODRIGUES, L.; ASSUNÇÃO, A.; MORTON, D.; TUCHSCHNEIDER, D.; FERNANDES, E. C. M.; MACEDO, M. N.; OLIVEIRA, U.; COE, M. T. The gathering firestorm in southern Amazonia. *Environmental Studies*, v. 6, n. 2, eaay1632, 2020.

BRASIL. Instituto Nacional de Pesquisas Espaciais. *PRODES*: incremento anual de área desmatada no Cerrado brasileiro. 2020. Available at: http://www.obt.inpe.br/cerrado. Access on: Mar. 20, 2023.

BRITO, A. U.; CHAVES, F. C. M.; OKA, J. M.; AZEVEDO, M. M. B.; BATISTA, A. C. Produção de biomassa aérea, teor e rendimento de extrato das folhas de crajiru [*Arrabidaea chica* (Bonpl.) B. Verl.] em função de adubação orgânica em Manaus, estado do Amazonas, Brasil. *Revista Brasileira de Plantas Medicinais*, v. 17, n. 3, p. 444-453, 2015.

CABRAL, J. S.; SCHURR, F. M. Estimating demographic models for the range dynamics of plant species. *Global Ecology and Biogeography*, v. 19, n. 1, p. 85-97, 2010.

CENTRO DE REFERÊNCIA E INFORMAÇÃO AMBIENTAL (CRIA). *SinBiota*: sistema de informação ambiental do Programa Biota/FAPESP. 2022. Available at: http://www.biotasp.org.br/sia/. Access on: Feb. 19, 2023.

DORMANN, C. F.; CALABRESE, J. M.; GUILLERA-ARROITA, G.; MATECHOU, E.; BAHN, V.; BARTOŃ, K.; BEALE, C. M. Model averaging in ecology: a review of Bayesian, information-theoretic, and tactical approaches for predictive inference. *Ecological Monographs*, v. 88, n. 4, p. 485-504, 2018.

ESRI, D. A. *Release 10*. Redlands: Environmental Systems Research Institute, 2011.

FAUSTO, M. A.; ANGELINI, L. P.; MARQUES, H. O.; SILVA FILHO, A.; MACHADO, N. G.; BIUDES, M. S. Impact of land-use change in the net radiation of the Cerrado of the southern Mato Grosso. *Ambiente e Água*, v. 11, n. 2, p. 350-361, 2016.

FERREIRA, R. B.; PARREIRA, M. R.; ARRUDA, F. V.; FALCÃO, M. J.; FREITAS, M.; NABOUT, J. C. V. Combining ecological niche models with experimental seed germination to estimate the effect of climate change on the distribution of endangered plant species in the Brazilian Cerrado. *Environmental Monitoring and Assessment*, v. 194, n. 4, e283, 2022.

FICK, S. E.; HIJMANS, R. J. WorldClim 2: new 1 km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, v. 37, n. 12, p. 4302-4315, 2017.

FIELDING, A. H.; BELL, J. F. A review of methods for the assessment of prediction errors in conservation presence/absence model. *Environmental Conservation*, v. 24, n. 1, p. 38-49, 1997.

FIRPO, M. A. F.; GUIMARÃES, B. S.; DANTAS, L. G.; SILVA, M. G. B. da; ALVEZ, L. M.; CHADWICK, R.; LLOPART, M. P.; OLIVEIRA, G. S. de. Assessment of CPIP6 models performance in simulating present day climate in Brazil. *Frontiers in Climate*, v. 4, e948499, 2022.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). *Crop prospects and food situation*. 2018. Available at: http://www.fao.org/giews/reports/. Access on: Jan. 21, 2023.

GLOBAL BIODIVERSITY INFORMATION FACILITY (GBIF). *Occurrence download*. 2022. Available at: https://www.gbif.org/pt/occurrence/search. Access on: Jan. 5, 2023.

GOMES, M. L.; BEZERRA, C. S.; AGUIAR, A. V. de; WREGE, M. S.; LOPES, M. T. G. Predição da distribuição natural e conservação de *Urena lobata* L. no Brasil. *Pesquisa Agropecuária Tropical*, v. 52, e72594, 2022.

GOMES, R. F.; ARRUDA, S. R.; ROSÁRIO, I. C. D.; ANDRADE, F. L. N.; MELLO, M. N. de; SANTOS, S. L. Amazon chicory: growing at full sunlight or under shade? *Horticultura Brasileira*, v. 41, e2554, 2023.

HIRATA, A. C. S.; HIRATA, E. K. Desempenho produtivo do agrião d'água cultivado em solo sob telas de sombreamento. *Pesquisa Agropecuária Brasileira*, v. 50, n. 10, p. 895-901, 2015.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). *Climate change*: the physical science basis. 2021. Available at: https://www.ipcc.ch/report/ar6/wg1/downl oads/report/IPCCAR6WGIFullReport.pdf. Access on: Dec. 19, 2022.

KELEN, M. E. B.; NOUHUYS, I. S.; KEHL, L. C.; BRACK, P.; SILVA, D. D. *Plantas alimentícias não convencionais (PANCs)*: hortaliças espontâneas e nativas. Porto Alegre: Ed. UFRGS, 2015.

KINUPP, V. F.; LORENZI, H. *Plantas alimentícias não convencionais (PANC) no Brasil*: guia de identificação, aspectos nutricionais e receitas ilustradas. São Paulo: Instituto Plantarum de Estudos da Flora, 2019.

LEITÃO, D. D. S. T. C.; SIQUEIRA, F. C.; SOUZA, S. H. B. de; MERCADANTE, A. Z.; CHISTE, R. C.; LOPES, A. S. Amazonian *Eryngium foetidum* leaves exhibited very high contents of bioactive compounds and high singlet oxygen quenching capacity. *International Journal of Food Properties*, v. 23, n. 1, p. 1452-1464, 2020.

LI, F.; LIU, Y.; YAN, W.; ZHAO, Y.; JIANG, R. Effects of future climate change on summer maize growth in Shijin irrigation district. *Theoretical and Applied Climatology*, v. 139, n. 1, p. 33-44, 2020.

LIBERATO, P. S.; LIMA, D. V. T.; SILVA, G. M. B. PANC: plantas alimentícias não convencionais e seus benefícios nutricionais. *Environmental Smoke*, v. 2, n. 2, p. 102-111, 2019.

LOHMANN, L. G. *Lista de espécies da flora do Brasil*: *Bignoniaceae*. 2015. Available at: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB112305. Access on: Dec. 23, 2022.

LORENZI, H.; MATOS, F. J. D. A.; CAVALLEIRO, A. D. S.; BROCHINI, V. F.; SOUZA, V. C. *Plantas medicinais no Brasil*: nativas e exóticas. São Paulo: Instituto Plantarum de Estudos da Flora, 2002.

MARENGO, J. A.; SOUZA JÚNIOR, C. *Mudanças climáticas*: impactos e cenários para a Amazônia. São Paulo: ALANA, 2018.

MERTENS, B.; POCCARD-CHAPUIS, R.; PIKETTY, M. G.; LACQUES, A. E.; VENTURIERI, A. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of São Félix do Xingu in south Pará. *Agricultural Economics*, v. 27, n. 3, p. 269-294, 2002.

MONTEVERDE, C.; SALES, F. de; JONES, C. Evaluation of the CMIP6 performance in simulating precipitation in the Amazon River basin. *Climate*, v. 10, n. 8, e122, 2022.

MUÑOZ, M. E. S.; GIOVANNI, R.; SIQUEIRA, M. F.; SUTTON, T.; BREWER, P.; PEREIRA, R. S.; CANHOS, D. A. L.; CANHOS, V. P. OpenModeller: a generic approach to species' potential distribution modelling. *GeoInformatica*, v. 15, n. 1, p. 111-135, 2011.

OLIVEIRA, D. P. C.; BORRÁS, M. R. L.; FERREIRA, L. C. L.; LÓPEZ-LOZANO, J. L. Anti-inflammatory activity of the aqueous extract of *Arrabidaea chica* (Humb. & Bonpl.) B. Verl. on the self-induced inflammatory process from venoms Amazonian snakes. *Revista Brasileira de Farmacognosia*, v. 19, n. 2, p. 643-649, 2009.

OMETTO, J. P.; AGUIAR, A. P. D.; MARTINELLI, L. A. Amazon deforestation in Brazil: effects, drivers, and challenges. *Carbon Management*, v. 2, n. 5, p. 575-585, 2011.

R DEVELOPMENT CORE TEAM. *R*: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2022.

REBELLO, K. M.; ALMEIDA, G. S. S.; BRITO, G. R. Modelagem de distribuição de *Moquiniastrum oligocephalum* (Gardner) G. Sancho (Asteraceae: Gochnatieae) para a Bahia, Brasil. *Peer Review*, v. 5, n. 19, p. 414-429, 2023.

REIS, C.; MATTEDI, M.; BARRIOS, Y. R. Mídias e desastres: panorama da produção científica internacional de 1996 a 2016. *Intercom: Revista Brasileira de Ciências da Comunicação*, v. 40, n. 2, p. 77-92, 2017.

RODRIGUES, T. L. M.; SILVA, M. E. P.; GURGEL, E. S. C.; OLIVEIRA, M. S.; LUCAS, F. C. A. *Eryngium Foetidum* L. (Apiaceae): a literature review of traditional uses, chemical composition, and pharmacological activities. *Evidence-Based Complementary and Alternative Medicine*, v. 2022, e2896895, 2022.

ROSERO-GÓMEZ, C. A.; ZAMBRANO, M. L.; GARCÍA, K. E.; VIRACOCHA, L. A. Nomenclatura y usos del culantro de monte (*Eryngium foetidum* L.) en la comunidade San Antonio de Padua, canton Quinsaloma, provincia de Los Ríos - Ecuador. *Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas*, v. 19, n. 3, p. 334-343, 2020.

RSTUDIO TEAM. *RStudio*: integrated development for R. Boston: RStudio, 2022.

SANTANA, M. M. M. de.; VASCONCELOS, R. N. de; MARIANO-NETO, E. Fire propensity in Amazon Savannas and rainforest and effects under climate change. *International Journal of Wildland Fire*, v. 32, n. 2, p. 149-163, 2022.

SILVA, F. C. N. S.; BEHR, K. R. V. Mudanças climáticas: desastre e negacionismo. *Revista Gestão em Conhecimento*, v. 6, n. 6, p. 1-12, 2021.

SILVA, G. M.; ROCHA, N. C.; SOUZA, B. K. M. de; AMARAL, M. P. C.; CUNHA, N. S. R. da; MORAES, L. V. S.; GEMAQUE, E. M.; DUTRA, C. D. T.; MOURA, J. S.; MENDES, P. M. O potencial das plantas alimentícias não convencionais (PANC): uma revisão de literatura. *Brazilian Journal of Development*, v. 8, n. 2, p. 14838-14853, 2022.

SILVA, L. F. L.; TECHIO, V. H.; RESENDE, L. V.; BRAZ, G. T.; RESENDE, K. F. M.; SAMARTINI, C. Q. Unconventional vegetables collected in Brazil: chromosome number and description of nuclear DNA content. *Crop Breeding and Applied Biotechnology*, v. 17, n. 4, p. 320-326, 2017.

SOBERÓN, J. M. Niche and area of distribution modeling: a population ecology perspective. *Ecography*, v. 33, n. 1, p. 159-167, 2010.

SOUSA, V. A. de; REEVES, P. A.; REILLEY, A.; AGUIAR, A. V. de; STEFENON, V. M.; RICHARDS, C. M. Genetic diversity, and biogeographic determinants of population structure in *Araucaria angustifolia* (Bert.) O. Ktze. *Conservation Genetics*, v. 21, n. 2, p. 217-229, 2020.

SPORBERT, M.; KEIL, P.; SEIDLER, G.; BRUELHEIDE, H.; JANDT, U.; AĆIĆ, S.; WELK, E. Testing macroecological abundance patterns: the relationship between local abundance and range size, range position and climatic suitability among European vascular plants. *Journal of Biogeography*, v. 47, n. 10, p. 2210-2222, 2022.

SUTHERLAND, W. J.; FRECKLETON, R. P.; GODFRAY, H. C. J.; BEISSINGER, S. R.; BENTON, T.; CAMERON, D. D.; CARMEL, Y.; COOMES, D. A.; COULSON, T.; EMMERSON, M. C.; HAILS, R. S. Identification of 100 fundamental ecological questions. *Journal of Ecology*, v. 101, n. 1, p. 58-67, 2013.

SUZUKI, J. C.; LAURENT, F.; ARAÚJO, V. B. *Transições produtivas, agroecológicas e culturais no campo brasileiro*. São Paulo: FFLCH/USP, 2019.

TERRA, S. B.; FERREIRA, B. P. Conhecimento de plantas alimentícias não convencionais em assentamentos rurais. *Revista Verde*, v. 15, n. 2, p. 221-228, 2020.

THOMAS, P. S.; ESSIEN, E. E.; NTUK, S. J.; CHOUDHARY, M. E. *Eryngium foetidum* L. essential oils: chemical composition and antioxidant capacity. *Medicines*, v. 4, n. 2, e24, 2017.

TOMAZ, J. S.; BEZERRA, C. de S.; AGUIAR, A.V. de; WREGE, M. S.; LOPES, M. T. G. Predição da distribuição natural, habitat e conservação de *Stryphnodendron pulcherrimum* (Willd.) Hochr. frente às mudanças climáticas globais. *Pesquisa Agropecuária Tropical*, v. 52, e72422, 2022.

TOURNE, D. C.; BALLESTER, M. V.; JAMES, P. M.; MARTORANO, L. G.; GUEDES, M. C.; THOMAS, E. Strategies to optimize modeling habitat suitability of *Bertholletia excelsa* in the Pan-Amazonia. *Ecology and Evolution*, v. 9, n. 22, p. 12623-12638, 2019.

TULER, A. C.; PEIXOTO, A. L.; SILVA, N. C. B. da. Plantas alimentícias não convencionais (PANC) na comunidade rural de São José da Figueira, Durandé, Minas Gerais, Brasil. *Rodriguésia*, v. 70, e01142018, 2019.

VANDERWAL, J.; SHOO, L. P.; JOHNSON, C. N.; WILLIAMS, S. E. Abundance and the environmental niche: environmental suitability estimated from niche models predicts the upper limit of local abundance. *The American Naturalist*, v. 174, n. 2, p. 282-291, 2009.

WICKHAM, H. *Tidyverse*: easily install and load the 'tidyverse'. R package version 1(1). 2017. Available at: https://cran.r-project.org/web/packages/tidyverse/index.html. Access on: June 19, 2023.

WREGE, M. S.; FRITZSONS, E.; SOARES, M. T. S.; BOGNOLA, I. A.; SOUSA, V. A. de; SOUSA, L. P. de. Distribuição natural e habitat da araucária frente às mudanças climáticas globais. *Pesquisa Florestal Brasileira*, v. 37, n. 91, p. 331-346, 2017.