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# *Genipa americana* L. GEOGRAPHIC OCCURRENCE IN BRAZIL

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**Resumo**

Por ser uma espécie arbórea bem recomendada para restauração de áreas degradadas, é necessário entender quais variáveis edafoclimáticas determinam a ocorrência de *Genipa americana* e em quais ambientes ela se tornaria mais adaptada. O objetivo deste trabalho foi realizar um levantamento da ocorrência de *Genipa americana* no Brasil e da influência de variáveis edafoclimáticas e de vegetação sobre sua distribuição. Para isso, o levantamento foi por meio da base de dados NeoTropTree, sendo utilizadas 19 variáveis ambientais para o estudo. Os dados foram submetidos à análise de componentes principais no RStudio, com os pacotes factoextra e ggplot2. As principais variáveis resultantes dessa análise foram aplicadas na elaboração de mapas, no programa ArcMap 10.5. Na análise de ocorrência geográfica, do total de 3.916 resultados de sites para o Brasil, a espécie *G. americana* esteve presente em 20,9% dos sites. O bioma predominante na ocorrência da espécie no país foi a Amazônia, concentrando 38,9% dos sites. Com relação aos limites ambientais, percebe-se que quanto menor a temperatura, menor a chance de ocorrência. A espécie está bem adaptada a altas temperaturas, precipitações anuais que variem de 1.000 a 2.500 mm, e baixos relevos. Com as mudanças climáticas iminentes, ela poderá ser empregada na restauração de regiões quentes. Entretanto, locais que são atualmente secos ou que estão ameaçados de se tornarem mais áridos ao longo dos anos, não são adequados para a espécie.
*Palavras-chave*: distribuição geográfica, jenipapo, variáveis climáticas.

**Abstract**

*Genipa americana* is a well-recommended tree species for the restoration of degraded areas, and it is necessary to understand which soil and climate variables determine its occurrence and in which environments it would become better adapted. The objective of this work was to survey the occurrence of *Genipa americana* in Brazil and the edaphoclimatic and vegetation variables' influence on its distribution. For this, the survey was carried out using the NeoTropTree database, using 19 environmental variables for the study. The data were submitted to principal component analysis in RStudio, with the factoextra and ggplot2 packages. The main variables from this analysis were applied in the map elaboration with the ArcMap 10.5 program. In the geographic occurrence analysis of 3,916 site results for Brazil, the species *G. americana* was present in 20.9% of the sites. The predominant biome in the species occurrence in the country was the Amazon, concentrating 38.9% of the sites. Regarding environmental limits, it is clear that the lower the temperature, the lower the chance of the species occurrence. The species is well adapted to high temperatures, annual rainfall ranging from 1,000 to 2,500 mm, and low reliefs. With climate change imminent, it could be used to restore warm regions. However, sites currently dry or threatened with becoming more arid over the years are unsuitable for the species.
*Keywords*: geographic distribution, genipap, climatic variables.

## INTRODUCTION

Tropical forest biodiversity depends on secondary formation forests, as most primary formations have already been altered (HANSEN *et al.*, 2013). These changes modify habitats, environmental conditions, and the forest composition structure, with the risk of compromising the long-term ecosystem maintenance, affecting diverse regions such as the Amazon and Cerrado (GOMES *et al.*, 2019; VELAZCO *et al.*, 2019).

Climatic variables are very influential in the forest community survival since, in many studies, plant species mortality due to climatic conditions is observed (HARTMANN *et al.*, 2018). According to Anderegg *et al.* (2020), the significant causes of forest disturbances resulting from climate change are fires, droughts, biotic agents (such as insects and pathogens), hurricanes, and frost.

The uncertainty as to whether future environmental conditions will be suitable for forests is a matter of concern for international environmental bodies (ANDEREGG *et al.*, 2020). However, vegetation adaptation guided by climate change can also cushion the impact that ecosystem services will suffer (TEMPERLI *et al.*, 2013). Therefore, it is necessary to know which environmental characteristics the species tolerate and the possible scenarios to which they would adapt, thus supporting the development of restoration projects for current and future degraded areas.

The geographic occurrence analysis of plant species is dependent on biotic and abiotic attributes and is also fundamental to assist in their management and recovery in natural environments (YUAN *et al.*, 2021). Abiotic variables, such as those representing the climate and soil, are conditioning factors for developing forest species (YUAN *et al.*, 2021). Still, studies that seek to expand the distribution knowledge of plant species beyond the already existing sample range are rare (MI *et al.*, 2017) due to the difficulty in disseminating and applying data collection methods, as even the species absence in the surveys is not certain (ELITH *et al*., 2006).

An influential native species for these projects, which requires a more significant collection of genetic information, is *Genipa americana* L., belonging to the Rubiaceae family and popularly known as genipap It is recommended for forest restoration programs (CAMPOS FILHO; SARTORELLI, 2015); however, there are insufficient studies dealing with its adaptive aspects associated with the spatial distribution of this forest species in Brazil.

The hypothesis addressed in this study is that environmental variables influence the occurrence of *G. americana* in Brazil. Therefore, this work aimed to survey the occurrence of *Genipa americana* in Brazil and the influence of edaphoclimatic and vegetation variables on its spatial distribution.

## MATERIAL AND METHODS

The occurrence survey of the species in Brazil was carried out using the NeoTropTree database (OLIVEIRA-FILHO, 2017), which uses plant species checklists distributed by locations (sites) throughout the Neotropical region. The sites in this database are circular areas with a 5 km radius, centered on the coordinates of the sources where information about the location was obtained. The species list for each location is composed of a taxonomic and occurrence lists combination in inventories (phytosociological spreadsheets), as well as information from herbaria. Therefore, from the available data, a spreadsheet was made available in the database with environmental variables for each location in the country, using 19 environmental variables for the study (Table 1).

Table 1. List of environmental variables extracted from the NeoTropTree database.
Tabela 1. Lista das variáveis ambientais extraídas da base de dados NeoTropTree.

| Variable | Abbreviations |
|---|---|
| Altitude | ALT |
| Phytogeographic domain | DOM |
| Ecoregion | ER |
| Climate regime | RC |
| Vegetation type | TV |
| Annual average temperature (°C) | TAn |
| Maximum temperature of the warmest month (°C) | TMax |
| Minimum temperature of the coldest month (°C) | TMin |
| Annual precipitation (mm) | PAn |
| Precipitation of the wettest month (mm) | PMU |
| Precipitation of the driest month (mm) | PMS |
| Duration of the period of water deficit (days) | DDH |
| Severity of the period of water deficit (mm) | SDH |
| Duration of the period of excess water (days) | DEH |
| Severity of the period of water excess (mm) | SEH |
| Rocky surface | SR |
| Soil drainage | DS |
| Soil water storage | AAS |
| Soil fertility | FS |

The selected locations were filtered in the NeoTropTree database, delimiting only those corresponding to the Brazilian territory. Subsequently, by consulting the list of species occurring in each available location in Brazil, the locations of *G. americana* were marked in this spreadsheet to gather information on which attributes characterize the species occurrence in Brazilian territory.

Data were submitted to principal component analysis (PCA) in RStudio (R CORE TEAM, 2020), with factoextra (KASSAMBARA; MUNDT, 2020) and ggplot2 packages (WICKHAM, 2016), in order to determine each variable statistical contribution to determine the species occurrence in each registered location. The variables were filtered to determine the minimum possible dimensions that explain at least 70% of the data obtained.

The main variables from this analysis were applied in the map elaboration, combined with the occurrence points of *G. americana* in Brazil obtained through geographic coordinates, for better visualization of the attribute's influence. The map elaboration was made in the ArcMap 10.5 program, with the environmental data from the spreadsheet itself made available in the database.

## RESULTS

Of the 3,916 results from sites for Brazil, the species *G. americana* was present in 818 sites, that is, in 20.9% of the sites. All Brazilian states registered the occurrence of genipap, except the Rio Grande do Sul and Santa Catarina. The predominant biome in the species occurrence in the country was the Amazon, concentrating 38.9% of the sites. The Atlantic Forest and the Cerrado concentrated 27.0% of the sites, leaving only 6.8% in the Caatinga (Figure 1).

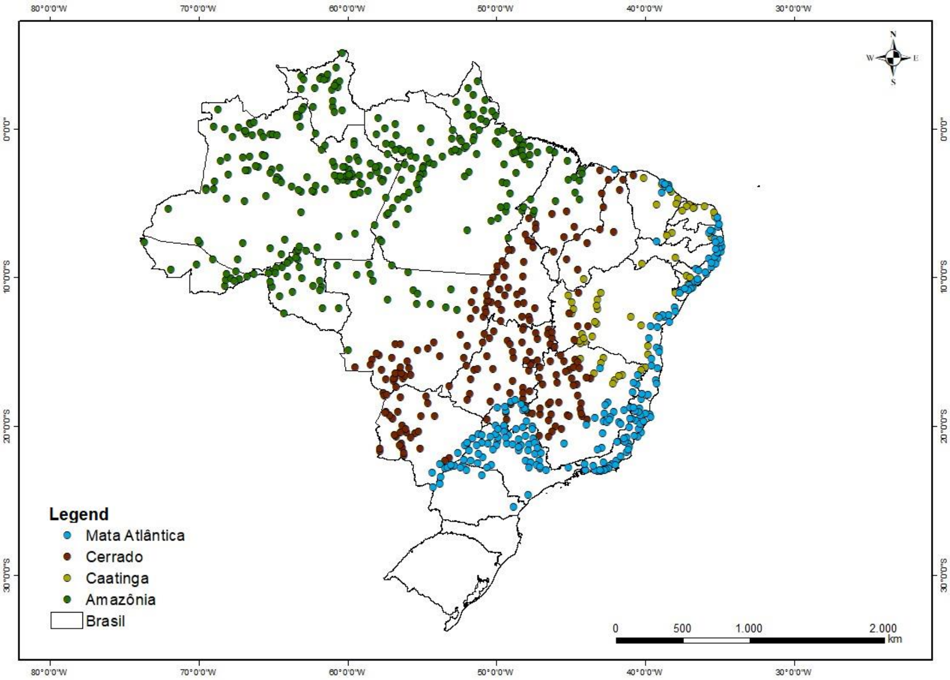



Figure 1. Occurrence site distribution of *Genipa americana* L. the Brazilian biomes, according to the NeoTropTree database (OLIVEIRA-FILHO, 2017).

Figura 1. Distribuição dos sites de ocorrência de *Genipa americana* L. nos biomas do território brasileiro, conforme a base de dados do NeoTropTree (OLIVEIRA-FILHO, 2017).

In the PCA analysis, the three primary dimensions explained 69.7% of the specie's distribution in Brazilian territory. However, as the first two dimensions already explain 61.3% of the data variation, only the first two components were considered to simplify the results visualization and interpretation in the biplot graph. The third axis insertion (3rd dimension), in this case, became unfeasible for interpretation.

In the first dimension, the variable that contributed the most was PAnn (10%), followed by SWE, DWE, TMin, PWM, CR, DOM, TAnn, ALT, PDM, and DWD, all with more than 5% of the contribution; the others contributed below this value. In the second dimension, with 20% of the contribution, there is the TMax. SWD had more than 15%, DWD, and TAnn more than 10%, and PDM, SD, and CR more than 5% (Figure 2).

Still, it is possible to observe from Figure 2a that the variables related to temperature and precipitation are present in a single principal component, as well as the edaphic variables with those of vegetation. Thus, these two sets influence the formation of three groups of *G. americana* occurrence sites (Figure 2b), one in each set of variables and a third between the sets.

Besides ALT, the only significant edaphic variable that positively influenced the *G. americana* occurrence in Brazil was SD, with 45% of sites classified as having good and moderately good drainage.

The variables used for data interpretation were TAnn, PAnn, ALT, and CR, as these are most commonly discussed in the literature.

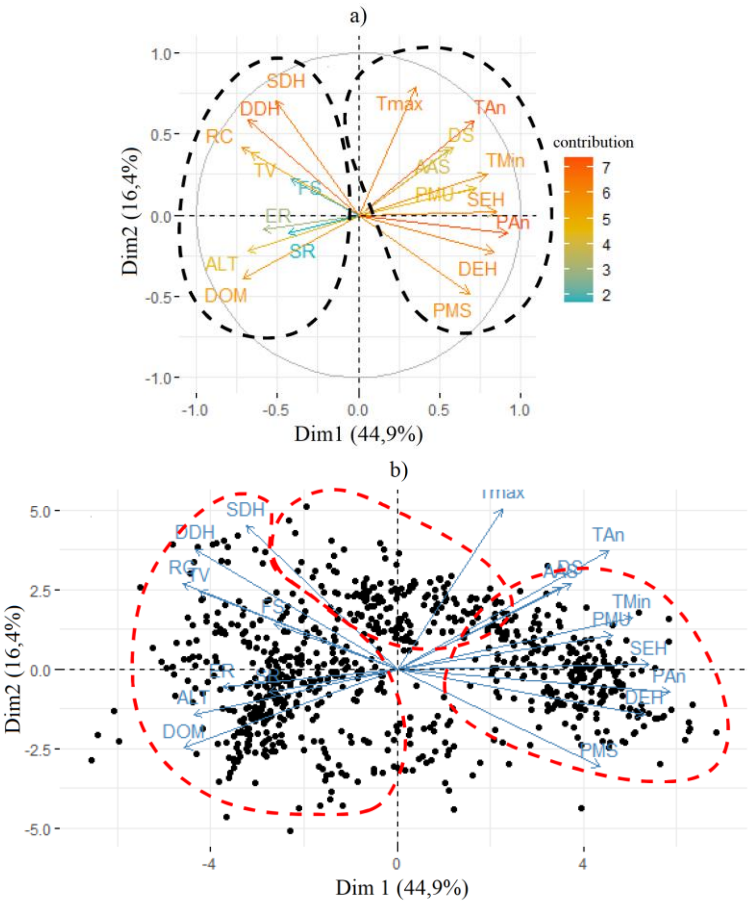



Figure 2. a) Main component of environmental variables and; b) Site number (locations) that are influenced by environmental variables in the main components that determine the *Genipa americana* L. occurrence in Brazilian territory, according to the NeoTropTree database (OLIVEIRA-FILHO, 2017).

Figura 2. a) Componente principal das variáveis ambientais e; b) Quantidade de sites (locais) que são influenciados pelas variáveis ambientais nos componentes principais que determinam a ocorrência de *Genipa americana* L. em território brasileiro, conforme a base de dados do NeoTropTree (OLIVEIRA-FILHO, 2017).

ALT: altitude; DOM: phytogeographic domain; ER: ecoregion; CR: climate regime; TV: type of vegetation; TAnn: mean annual temperature (°C); TMax: maximum temperature of the warmest month (°C); TMin: minimum temperature of the coldest month (°C); PAnn: annual precipitation (mm); PWM: precipitation of the wettest month (mm); PDM: precipitation of the driest month (mm); DWD: duration of the water deficit period (days); SWD: severity of the water deficit period (mm); DWE: duration of water excess period (days); SWE: severity of the period of water excess (mm); RS: rocky surface; SD: soil drainage; SWS: soil water storage; SF: soil fertility.

Analyzing the data provide by NeoTropTree (OLIVEIRA-FILHO, 2017), in Brazil the average annual temperature where *G. americana* occurs was 24.9 °C, with an average maximum of 27.9 °C and an average minimum of 18.2 °C. The average annual precipitation of these places is 1,677.9 mm, with an average maximum of 3,622 to 509 mm. The *G. americana* occurrence varies from areas with 3 to 1,071 m altitude, with an average of 266.3 m.

Regarding the environmental limits for the *G. americana* occurrence in Brazil, the lower the temperature, the lower the chance of occurrence, with 79 sites (9.0%) in the annual average temperature range of 18 to 22 °C. The species presence is observed in the hottest places in the country, with 335 sites (40.9 %) in the 26 to 28 °C class, and 68.2 % (558) if the 24 to 26 °C class is also considered (Figure 3a).

The sites distribution concerning annual precipitation does not have the same behavior as the distribution concerning temperature, with 333 sites (40.7%) in the second class ranging from 1,005 to 1,504 mm, decreasing gradually as precipitation increases, concentrating the species occurrence in the second, third and fourth classes (1,005 to 2,504 mm) (Figure 3b).

The altitude distribution is inverse to the average annual temperature distribution, with 367 sites (44.8%) in the first altitude class (3 to 152 m), with a lower species occurrence at higher altitudes (Figure 3c).

The NeoTropTree database classifies the climate regime into arid, semi-arid, cloudy, maritime, rainy, seasonally cold, and seasonally dry. There was no *G. americana* occurrence in arid, seasonally cold, and cloudy regions, and only 39 sites (0.47%) in maritime (19; 0.23%) and semi-arid (20; 0.24%) regimes. The highest occurrence level occurred in the seasonally dry regime, with 495 occurrence records (60.5%) and 284 (34.7%) in the pluvial (Figure 3d).

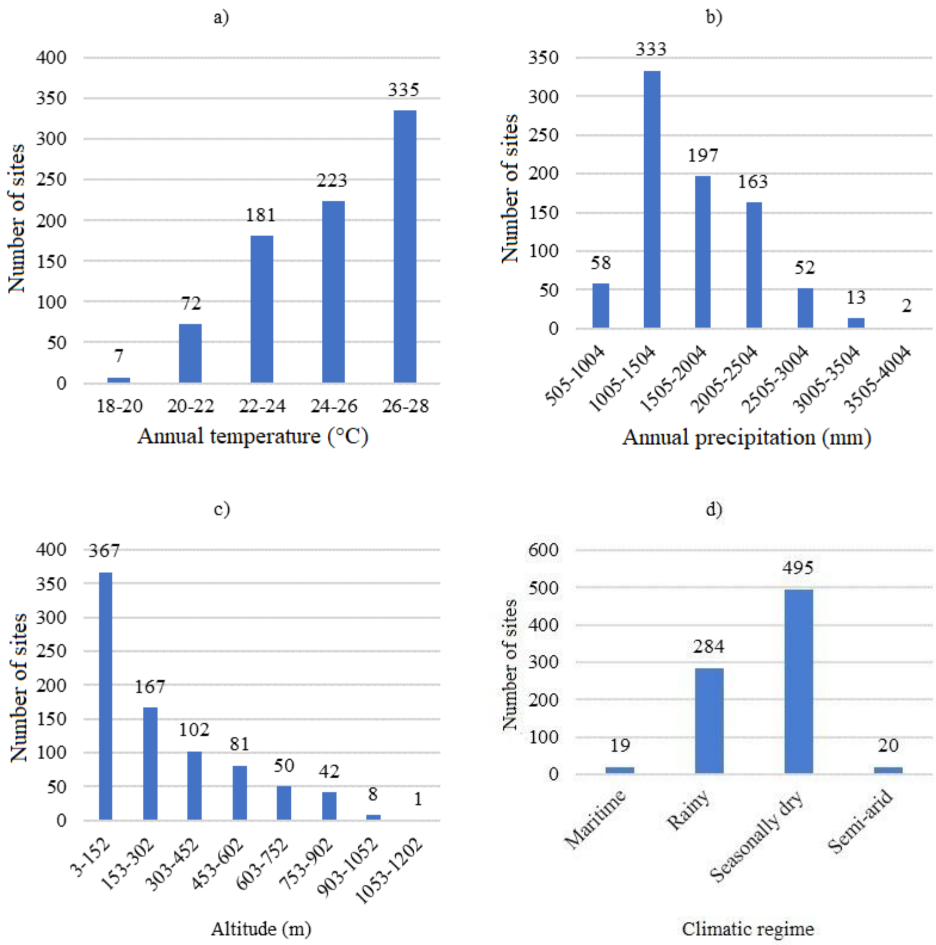


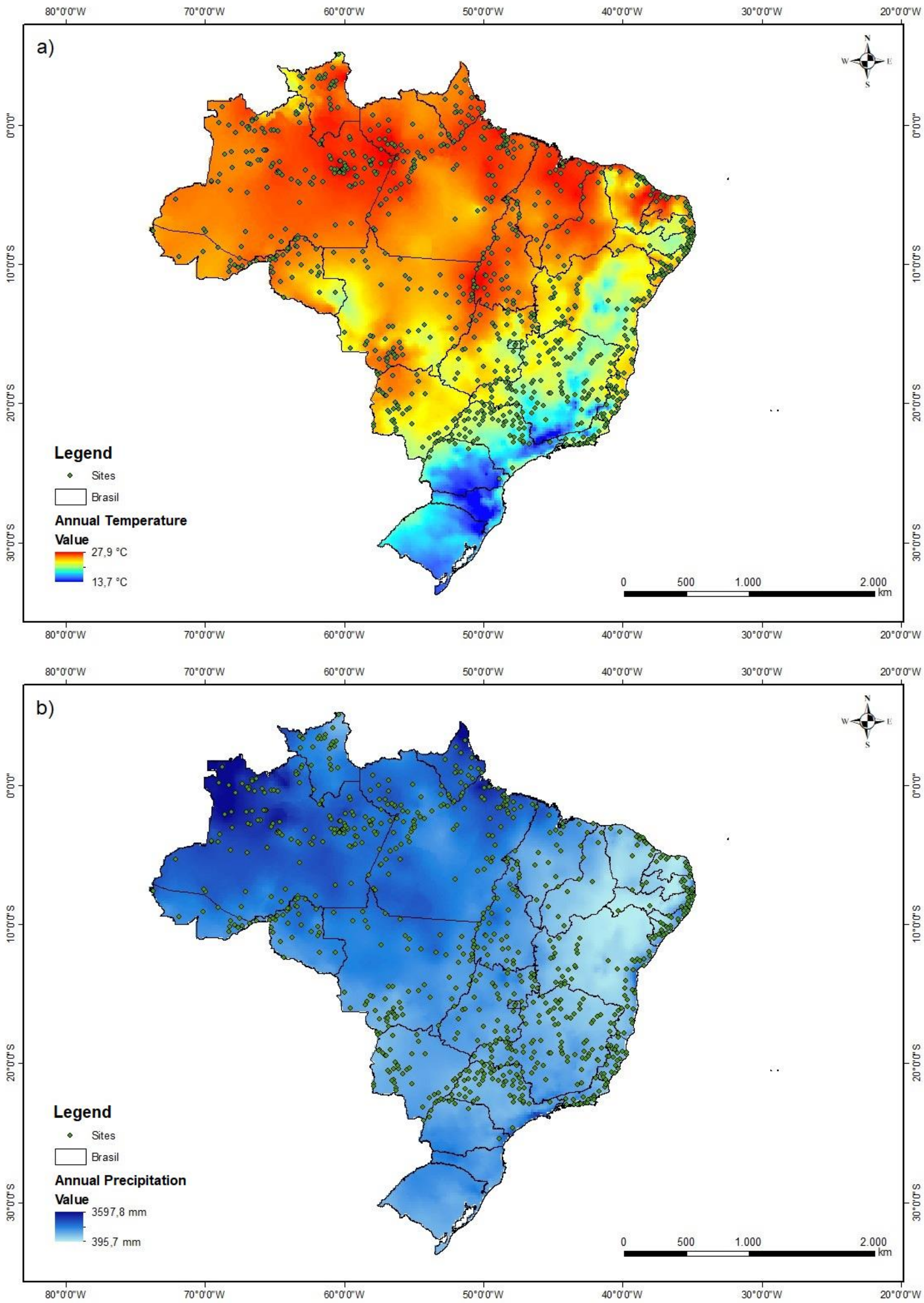

Figure 3. Site number of *Genipa americana* L. occurrence in Brazilian territory by a) average annual temperature; b) annual precipitation; c) altitude; and d) climate regime, according to the NeoTropTree database (OLIVEIRA-FILHO, 2017).

Figura 3. Quantidade de sítios de ocorrência de *Genipa americana* L. em território brasileiro por a) temperatura média anual; b) precipitação anual; c) altitude; e d) regime climático, conforme a base de dados do NeoTropTree (OLIVEIRA-FILHO, 2017).

By observing the maps generated of the *G. americana* occurrence from the environmental variables (Figure 4), it is possible to determine that the species does not occur in the country's extreme south because it does not tolerate average annual temperatures below 18 °C and seasonally cold regions.

It also has little distribution in the Caatinga because, despite the high temperatures, it does not occur in semi-arid regions with low precipitation (< 509 mm). In addition, it is possible to observe other areas without species in central Bahia, south of Minas Gerais, and southeast of Paraná and Santa Catarina, which have higher altitudes, since the specie's presence is almost null at altitudes greater than 1,000 m.

Other country regions with infrequent *G. americana* occurrence, such as central-west Amazonas (Amazon River depression), southern Pará (southern Amazon plateaus), and western Mato Grosso (Chapada), can also be explained by the altitude variety due to the relief formation of these areas, characterized by steeper slopes or even by erosion.


a)
Legend
Sites
Brasil
Annual Temperature
Value
27,9 °C
13,7 °C
0 500 1.000 2.000 km
b)
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Sites
Brasil
Annual Precipitation
Value
3597,8 mm
395,7 mm
0 500 1.000 2.000 km

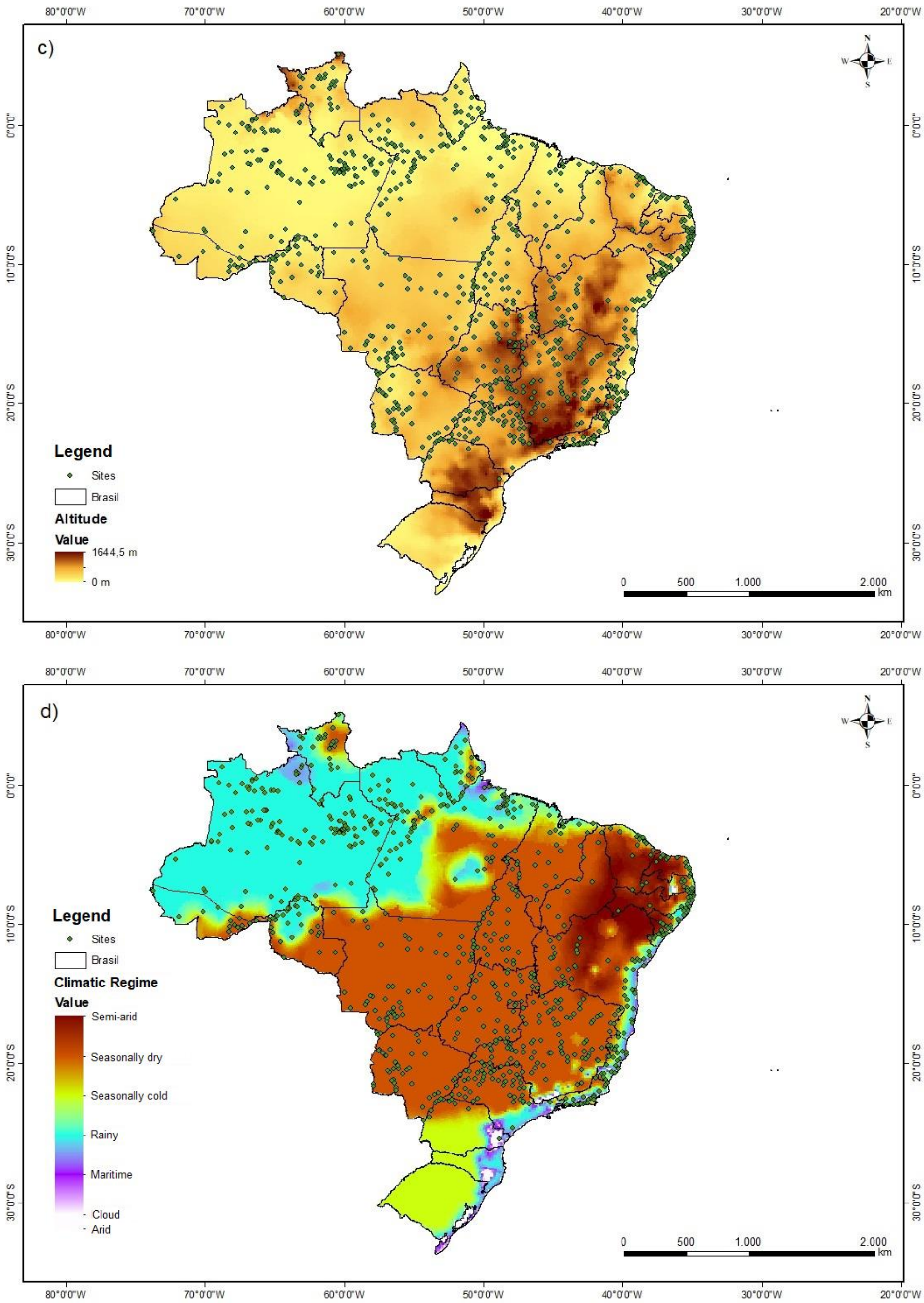


Figure 4. Environmental variables maps concerning the *Genipa americana* L. occurrence sites in Brazilian territory, as follows: a) annual average temperature; b) annual precipitation; c) altitude; and d) climate regime, according to the NeoTropTree database (OLIVEIRA-FILHO, 2017).

Figura 4. Mapas das variáveis ambientais em relação aos sítios de ocorrência de *Genipa americana* L. em território brasileiro, sendo: a) temperatura média anual; b) precipitação anual; c) altitude; e d) regime climático, conforme a base de dados do NeoTropTree (OLIVEIRA-FILHO, 2017).

## DISCUSSION

*G. americana* is a semideciduous heliophyte plant, occurring mainly in humid areas (DONADIO *et al.*, 2004). It is considered late secondary, with dispersion by barochory, hydrochory, and zoochory and pollination by bumblebees (CARVALHO, 2003). In addition to interacting with the fauna through dispersion and pollination, the species also serves as a food source for birds, turtles, and primates (RAGUSA-NETTO, 2015; CUNHA *et al.*, 2020; VALENTA *et al.*, 2015). This information is essential for restoration projects since it shows *G. americana* as a macrofauna maintainer in different phytophysiognomies and justifies its wide distribution through dispersion in different regions.

Based on the literature on the areas of *G. americana* occurrence and the geographic distribution patterns (CARVALHO, 2003; RIBEIRO, LIMA, 2009), the species distribution pattern can be classified as neotropical (which occurs in South America and Central and extends to Mexico), with generalist species standing out in this pattern. Therefore, *G. americana* can be considered a generalist species, as it occurs from Mexico to distinct formations such as the Cerrado.

Brazil has a maximum average annual temperature of 27.9 °C and a minimum average of 11.3 °C, with the highest temperatures in the North/Northeast regions and the lowest in the South/Southeast. The annual rainfall ranges from 372 to 3,731 mm, with the country's northern region having the highest rainfall and the Northeast the lowest (OLIVEIRA-FILHO, 2017).

The most used climatic variables to understand the tropical flora biodiversity distribution are temperature and water availability (GASTON, 2000). The wide *G. americana* distribution in Brazilian territory is due to the species being considered a generalist, with tolerance to a high climatic factors' amplitude, considering the results obtained in Figure 3. Regarding the species' presence in different climatic types, Hawkins *et al.* (2005) establish that the environment and the dynamics involved in the physiological species processes are determinant in their geographic distribution and, therefore, when there is a wide distribution, it is a consequence of the interaction between the organism's characteristics and environmental gradients.

In plants, the net photosynthetic rate is reduced, while respiration increases in high-temperature conditions associated with drought (TESKEY *et al.*, 2015). These conditions' combination can be observed in the Brazilian Northeast, in the Agreste and Sertão portion of the country. Also, according to Teskey *et al.* (2015), places with lower precipitation rates cause an increase in the sensible soil heat and a reduction in the air relative humidity, consequently increasing the temperature, evapotranspiration and resulting in the worsening of the drought level due to faster soil drying. Therefore, as *G. americana* preferentially occupies areas where humidity is relatively high, including flood tolerance (PIRES *et al.*, 2018), the country's semi-arid region does not offer all the environmental conditions it requires.

Drainage is positively correlated with soil water storage. However, it has a more significant contribution to the species occurrence due to its direct relationship with the severity and duration of periods of water excess and deficit, as well as with annual precipitation (KUMAR et *al*., 2021).

In the work of Pessoa *et al.* (2021), edaphic variables influenced the species' abundance, composition, and diversity in the Cerrado and the Amazon through the soil's physical and chemical properties, geographic isolation, and floristic influences on the two biomes. Therefore, considering that edaphic conditions are essential for the forest species occurrence, it is possible to suggest that *G. americana* has good adaptation to the variability of rock surface levels, water storage, and soil fertility present in Brazil since they did not limit its distribution in the territory. This information corroborates Carvalho's (2003) work, which described *G. americana* as a species that grows best in well-drained soils, but is generally undemanding regarding the soil's physical properties.

## CONCLUSIONS

Our analyzes allow us to conclude that:

- The species *G. americana* is well adapted to high temperatures, annual rainfall ranging from 1,000 to 2,500 mm, and low reliefs.
- With climate change imminent, it could be used to restore warm regions.
- The *G. americana* occurrence was highlighted in areas of well-drained soils, however, without significant influence of the other edaphic variables.
- Therefore, sites currently dry or threatened with becoming more arid over the years are unsuitable for the species.
- This information increases the *G. americana* recommendation for forest restoration projects, being a species of possible adaptation to climatically altered regions.

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