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Research Article

Dicrananthera hedyotidea C. Presl. (Melastomataceae) in Maranhão state, Brazil: first record and ecological niche model of the species

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Dicrananthera C. Presl. is a monospecific genus of the tribe Marcetieae, comprising perennial herbs typically occurring in areas adjacent to wetlands. The species exhibits a disjunct distribution, with confirmed records in both the Amazon and Atlantic Forest domains. *Dicrananthera hedyotidea* is morphologically distinct from other genera within the tribe by the presence of dimorphic stamens bearing subulate ventral appendages. This study reports the first occurrence of *D. hedyotidea* in the state of Maranhão, and provides a taxonomic treatment, an updated geographical distribution, and an ecological niche model for the species in South America. The potential distribution was estimated using species distribution modeling (SDM) techniques implemented in the R software environment. This new record extends the known range and improves the understanding of the species' distribution in Maranhão, underscores the floristic diversity of the Baixada Maranhense region, and reinforces the importance of further botanical surveys and conservation efforts in this part of Brazil.

Keywords: Baixada Maranhense, ecological niche modeling, Marcetieae, northeastern Brazil, taxonomy.

Introduction

Melastomataceae is a family with a wide tropical/subtropical distribution, being the fifth most diverse in Brazil, with 69 genera and approximately 1440 species, of which 949 are endemic. The family occurs in all states of the country and is concentrated in the phytogeographic domains of the Cerrado, Atlantic Forest, Amazon, and Rupestrian Fields (Baumgratz et al. 2006, Goldenberg et al. 2020, Scheidegger and Rando 2024).

The genus *Dicrananthera* C. Presl. is monospecific, belongs to the tribe Marcetiae, and was segregated from *Acisanthera* P.Brown after molecular and morphological studies.

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Composed of annual herbs from wetlands, *Dicrananthera* is distinguished by its 4-merous flower and dimorphic stamens (with two subulate ventral appendages on the stamens before the sepals) and a 2-locular ovary, being morphologically distinct from *Acisanthera*, which has 5-merous flowers, non-dimorphic stamens, and a 3-locular ovary.

Due to the rarity of *Dicrananthera hedyotidea* and the limited number of records available in herbaria, its true geographic distribution is likely underestimated. Species with sparse and spatially biased records are particularly suitable for species distribution modeling (SDM), since these approaches allow the integration of occurrence data with environmental predictors to infer potential areas of ecological suitability (Elith and Leathwick 2009, Peterson et al. 2011).

In this context, SDM represents an important tool for 1) identifying environmentally suitable regions that remain undersampled, 2) assessing whether apparently disjunct populations reflect true biogeographical discontinuities or sampling gaps, and 3) generating testable hypotheses about the ecological requirements of narrowly distributed species. For *D. hedyotidea*, whose known distribution is fragmented and based on few historical collections, SDM provides a robust framework for interpreting new distribution records within a broader biogeographical context to guide future field surveys.

In northeastern Brazil, the state of Maranhão harbors remarkable floristic diversity due to its position within a transition zone between the Amazon and Cerrado biomes (Silva et al. 2022). This ecotonal setting contributes to the high species richness of Melastomataceae, a family that includes a wide range of life forms such as trees, shrubs, subshrubs, herbs and, more rarely, lianas and epiphytes (Goldenberg et al. 2012).

Despite being a family commonly cited in floristic studies in the state of Maranhão (Almeida Jr et al. 2017, Lima and Almeida Jr 2018, Guterres et al. 2019, 2020, Serra and Almeida Jr 2021), there is still a knowledge gap regarding the flora, ecology, and taxonomy of Melastomataceae. The present study reports the first record of *D. hedyotidea* for Maranhão state. It provides taxonomic treatment, updated geographic distribution, and an ecological niche model for the species in South America, aiming to enhance the understanding of the distribution patterns of rare or poorly collected taxa.

Material and methods

Study area

The species was collected in the Quilombola community of Monte Palma, a rural locality in the municipality of Bequimão, northwestern Maranhão state, at the following coordinates: 02°26′09.22″S, 44°51′39.42″W (Fig. 1 and 2). Bequimão lies within two important conservation units of the state: the Área de Proteção Ambiental da Baixada Maranhense (Environmental Protection Area of Baixada Maranhense), established by State Decree no. 11.900 of 11 June 1991, in recognition of its exceptional biodiversity (Maranhão 1991), and the Área de Proteção Ambiental das Reentrâncias Maranhenses, created by State Decree no. 11.90 of November 1991 (MMA 2013).

The Baixada Maranhense region exhibits unique hydrological characteristics influenced by strong local seasonality, with alternating flooding and drought periods that shape its landscape. This seasonality supports high biodiversity, encompassing a network of lacustrine basins in northeastern Brazil and a mosaic of lowlands, flat and seasonally flooded grasslands, gallery forests, and mangroves (Costa Neto et al. 2014, Arouche 2021). These features have led to

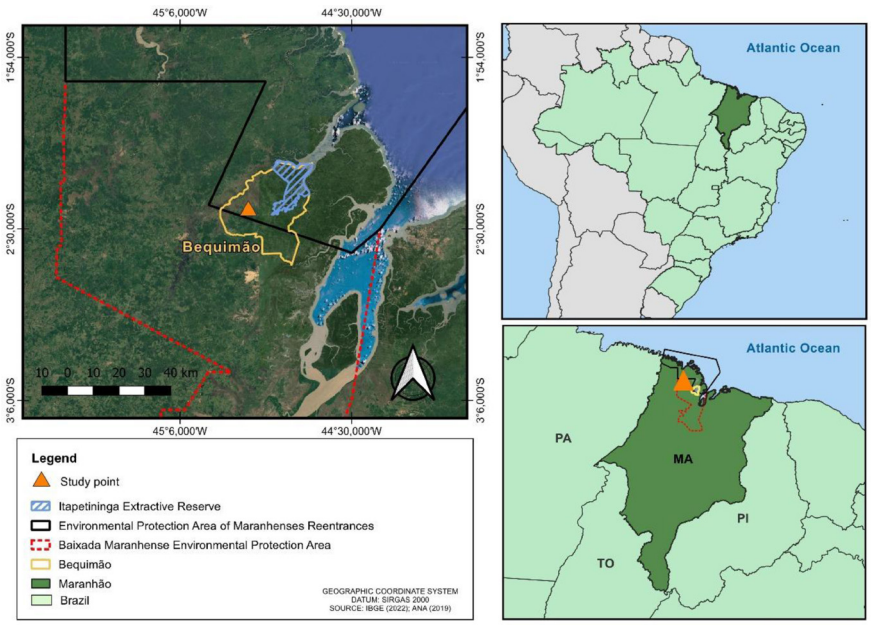


Figure 1. Location map of the study area, municipality of Bequimão, Maranhão, Brazil.



Figure 2. Vegetation surrounding the Quilombola community of Monte Palma, municipality of Bequimão, Maranhão, Brazil. Photos by Sandro Marcio.

the designation of Baixada Maranhense as both a Ramsar Site and an Environmental Protection Area (APA) for sustainable use, given that most of the local population depends on subsistence agriculture (Ibañez 2000, Tozato 2017, Ribeiro et al. 2020, Arouche 2021, Amorim et al. 2022).

The region presents a markedly seasonal landscape throughout the year, characterized by a tropical climate (Aw) according to the Köppen classification (Álvares et al. 2013). The rainy season extends from January to June, with an average monthly precipitation of 268.8 mm, followed by a dry period from July to December. The mean annual temperature is approximately 28°C, ranging from 24 to 32°C, and annual precipitation varies between 1855.7 and 2000 mm (INMET 2020).

Collection and identification of material

Specimens of *D. hedyotidea* were collected in June 2024 during an expedition to conduct a floristic survey. The species was found only once during exploratory walks in the study area (Santos Junior et al. unpubl.). Despite being a wetland environment, the area was traversed to increase the sampling effort for the floristic survey. However, it should be noted that despite the collection efforts carried out in other months of 2024, no more individuals of *D. hedyotidea* were found in the area.

The herborization process followed the protocol described by Peixoto and Maia (2013). After collection, the material was transferred to the Laboratório de Estudos Botânicos (LEB) of the Federal University of Maranhão (UFMA) for identification using specialized literature (Goldenberg 2012, Rocha et al. 2016, 2018, Silva 2023). Morphological descriptions followed the terminology of Harris and Harris (2001).

Information on species occurrences was gathered from the platforms *Flora e Funga do Brasil* (https://floradobrasil.jbrj.gov.br), *Specieslink* (https://specieslink.net/), and *SiBBr* (http://sibbr.gov.br/). After analysis, voucher specimens will be deposited in the Maranhão Herbarium (MAR) (Almeida Jr 2015) at UFMA.

For this study, only georeferenced records confirmed by specialists and available in the SpeciesLink database (2025) and SiBBr (52) under the name *Dicrananthera hedyotidea* C. Presl. were considered, as well as its synonyms *Acisanthera hedyotidea* (K. Presl.) Triana, *Acisanthera salzmannii* (Naudin) Cogn., and *Acisanthera boissieriana* Cogn., following the nomenclatural treatment of *Acisanthera* proposed by Guimarães et al. (2017).

Geographical distribution modeling

To better understand the distribution of the species, an ecological niche modeling analysis was carried out for South America to elucidate its geographic range and to support future research on taxa with few collection records. The potential distribution modeling was conducted using species distribution modeling (SDM) techniques implemented in the R software environment (www.r-project.org). Occurrence data were retrieved from the Global Biodiversity Information Facility (GBIF) through the 'dismo' package (Hijmans et al. 2024), selecting only verified records corresponding to herbarium specimens to ensure data accuracy and reliability.

Data were organized in an Excel spreadsheet, including only records with valid geographic coordinates. Duplicates and records with missing information were removed to maintain spatial data quality (Elith et al. 2006). Subsequently, a second filter was applied to exclude outlier coordinates and those located outside the known distributional range of the species. These exclusions were determined through visual inspections using Google Earth and QGIS. A final verification ensured that all selected records included specimen photographs and determinations made by qualified taxonomists confirming species identity. After data cleaning, 17 georeferenced occurrence points were retained.

All spatial data layers and occurrence records were standardized to the WGS84 geographic coordinate system (EPSG:4326). Environmental variables comprised 19 bioclimatic and one elevation variable obtained from WorldClim (Fick and Hijmans 2017), as well as eight edaphic variables from the Harmonized World Soil Database ver. 2.0 (Fao and Liasa 2023), totaling 28 environmental predictors. All variables were obtained in raster format and tested for multicollinearity using the variance inflation factor (VIF) through the 'usdm' package (Naimi et al. 2014). A conservative VIF threshold of less than 5 was adopted, and collinear variables were excluded prior to model calibration to reduce redundancy and minimize potential model overfitting, following the recommendations of Dormann et al. (2013). Background pseudo-absence points were randomly generated within the study area using the 'dismo' package (Hijmans et al. 2024) to characterize the range of available environmental conditions and contrast them with known occurrence points.

For predictive modeling, the gradient boosting machine (GBM) algorithm was employed using the GBM package (Ridgeway et al. 2024). The algorithm applies boosted regression trees (BRT) for prediction and was selected due to its high performance in modeling species distributions, particularly its ability to capture non-linear relationships and complex interactions among environmental variables (Elith et al. 2008). The GBM model was parameterized with tree complexity = 5, learning rate = 0.001, bag fraction = 0.5, and a maximum of 20 000 trees (Elith et al. 2008).

Model performance and variable importance were evaluated within the GBM framework. Model evaluation was conducted using a k-fold cross-validation procedure, and predictive performance was assessed through receiver operating characteristic (ROC) curves and corresponding area under the curve (AUC) values (Fielding and Bell 1997), generated with the 'pROC' package (Robin et al. 2011). Raster processing was performed using the 'raster' package (Hijmans 2025), and spatial data manipulation and visualization were conducted using 'sf' (Pebesma 2018) and 'sp' (Bivand et al. 2013).

Results and discussion

This study reports the first occurrence of *D hedyotidea* in the state of Maranhão, within the Amazonian sector of the state. The species was recorded in a transitional area of northern Brazil, located in the easternmost portion of the Amazonian domain of Maranhão, between two environmental protection areas: the APA das Reentrâncias Maranhenses and the APA da Baixada Maranhense. *Dicrananthera hedyotidea* exhibits a disjunct distribution, with confirmed occurrences in northern Brazil (Amazon biome) and in northeastern Brazil (Atlantic Forest areas) (Silva et al. 2023).

Taxonomic treatment

Dicrananthera hedyotidea C. Presl, Symb. Bot. 1: 76. 1832. Type: Brazil, Bahia, Lhotsky, sn. (PRC450611) (Fig. 3).

Description

Annual herb, 25–30 cm tall; branches cylindrical, covered with glandular indument and simple trichomes, white to brownish. Leaves opposite, simple, subsessile, membranaceous; apex attenuate, base decurrent to attenuate, margin serrate; venation (5) basal acrodromous; leaf blades 0.4–2.5 × 0.2–1.5 cm, ovate, discolorous, adaxial surface glabrous, abaxial surface with simple trichomes restricted to the main vein, domatia absent. Flowers solitary, axillary and terminal; pedicel 1–6 mm long; sepals (4) 1.5–2.0 × 0.8–1.0 mm, glabrous, triangular, with elongated lobes; petals (4) pink, 2.5–3.0 × 1.0–1.5 mm; hypanthium globose. Stamens 3–5 mm long, dimorphic (8 in total), arranged in two whorls; antesepalous stamens with yellow, bisubulate connectives, curved anthers with purple thecae, poricidal, filaments yellow and glabrous; staminodes absent. Stigma terminal, apex spongy; ovary inferior, 2-locular, multiovulate; fruit a capsule, 3.5–5.5 × 2–3 mm, with persistent calyx; seeds cochleate, ca 0.3 mm long, striate.

Phenology

Annual herb, collected in June with flowers and fruits.

Distribution and habitat

Brazil (north and northeast), Bolivia, Colombia, Guyana, Suriname, and Venezuela. Commonly found in savannas, flooded areas, and forest margins.

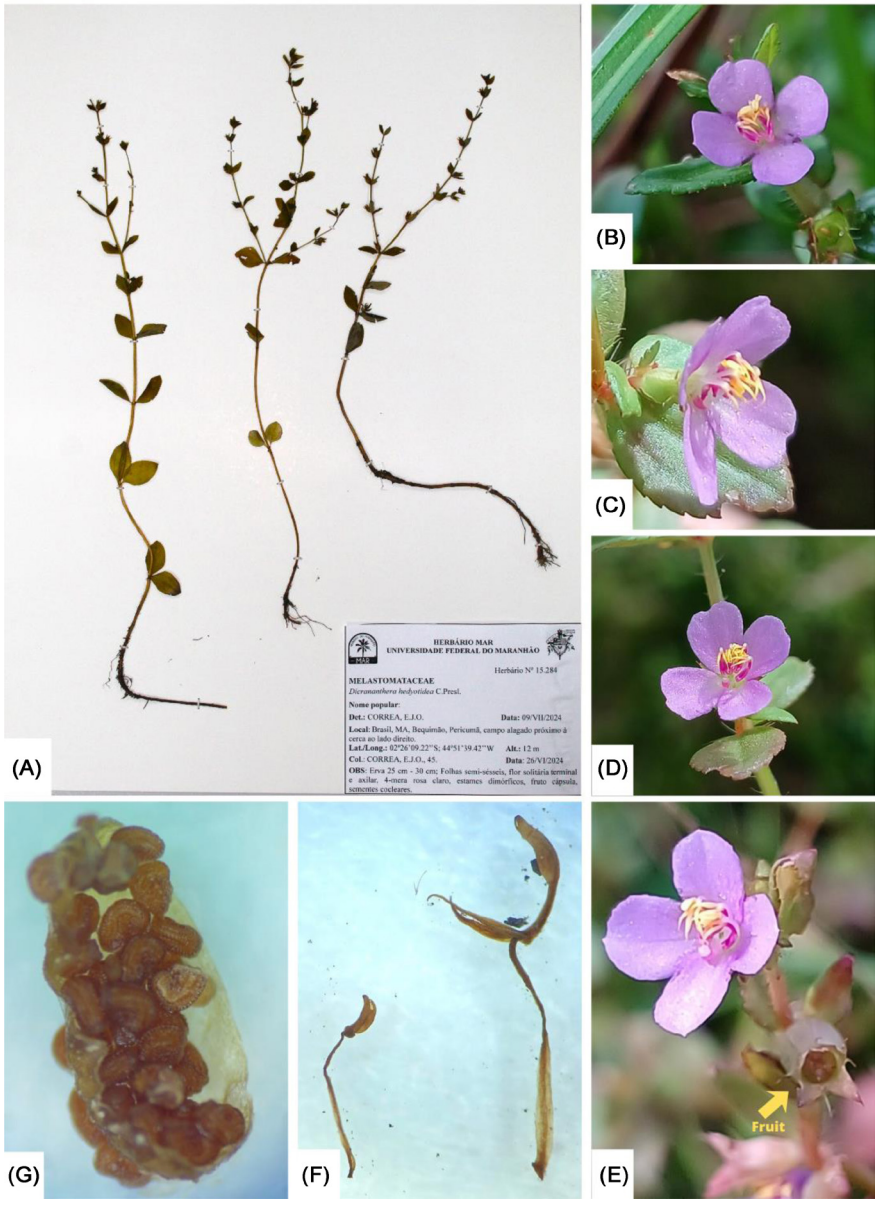


Figure 3. *Dicrananthera hedyotidea*. (A) Herbarium specimen, showing habit and phyllotaxy; (B)–(E) flower, stamens, and capsule-type fruit; (F) and (G) view under a magnifying glass: dimorphic stamens (ante-sepal stamen with bisubulate connective) and cochleate seeds, respectively.

Similar species

Although *D. hedyotidea* resembles *Rostranthera tetraptera* (Cogn.) M. J. R. Rocha & P. J. F. due to the 4-merous flowers and 2-locular ovary, the morphology of the stamens of the first (bisubulate with curved anthers) and seeds (cochlear) is quite distinct from the second (versus subulate stamens, rostrate anthers, and reniform seeds). The species also differs from the taxa that make up the genera *Acisanthera* P.Browne and *Noterophila* Mart., whose flowers are 5-merous (versus 4-merous flowers) and the ovary 2-3-locular (versus 2-locular ovary) (Rocha et al. 2018).

Examined material

Brazil, Maranhão: Povoado de Pericumã, Bequimão, 26 June 2024, fl. and fr., E.J.O. Correa 45 (MAR).

Additional material examined

Brazil, Bahia: Fazenda Rio do Negro, Entre Rios, 28 Aug. 2013, (fl.), A.V. Popovkin & J. C. Mendes 1526 (AFR, HUEFS, IBIUEMG). Fazenda Rio do Negro, Entre Rios, 5 July 2010, (fl.), A. V. Popovkin 720 (HUEFS). Brazil, Paraíba: Forte Velho, Santa Rita, 2 July 2012, (fl.), C. M. L. R. Araújo & M. F. M. Brito 280 (BHCB, UFP). Brazil, Pernambuco:

Bongi, Recife, 22 July 1961, (fl.), E. Pereira 5743 (PEL). Tapera, 15 Apr. 1905, (fl.), B. J. Pickel 3094 (US). Escola Pernambuco, 26 July 1924, B. Pickel 776 (SP). Jaqueira, RPPN Frei Caneca, 14 Dec. 2010, (fl.), G. A. Gomes-Costa 222 (NYBG). Saltinho, Pernambuco, 2 Nov. 1951, (fl.), J. Falcao, W. A. Egler & E. Pereira 897 (US). RPPN Frei Caneca, Jaqueira, 17 July 2010, (fl.), M.A. Chagas 52 (JPB). RPPN Frei Caneca, Jaqueira, 14 Dec. 2010, (fl.), S.O. Santos 222 (JPB). Brasil, Mato Grosso: Estrada de Barra do Bugres, Cáceres, 3 June 1988, (fl.), Ordonio 3 (SJRP).

Dicrananthera hedyotidea is an annual herb occurring in flooded grasslands or savannas and along forest margins. It can be recognized by its tetramerous flowers and strongly dimorphic stamens with bifurcate connectives and subulate appendages, as well as by its two-locular ovary. The specimen analyzed was collected with flowers and fruits during the rainy season, in June.

Records of *D. hedyotidea* in South America are concentrated in Brazil, Bolivia, Colombia, Guyana, Suriname, and Venezuela (Silva 2023, GBIF 2025, continuously updated), all within the Amazonian biome. In Brazil, the species has confirmed occurrences in the north (Roraima), northeast (Alagoas, Bahia, Paraíba, and Pernambuco), and central-west (Mato Grosso) regions, encompassing both the Amazon and Atlantic Forest domains (Rocha et al. 2016, 2018, Flora do Brasil 2024) (Fig. 4).

In Maranhão, the Baixada Maranhense remains an undersampled region with limited floristic investigations (Forzza et al. 2012, Sousa-Baena et al. 2014, Arouche 2021, Oliveira et al. 2022). This is evident from the low number of specimens represented in online herbarium databases (Flora e Funga do Brasil 2025, GBIF 2025, SpeciesLink 2025). The scarcity of collections may reflect the lack of logistical support and funding for large-scale botanical expeditions in this part of northeastern Brazil (Oliveira et al. 2022).

Dicrananthera hedyotidea was first collected in Brazil in 1905, in the municipality of Tapera, state of Pernambuco (voucher US 1571809). Pernambuco currently holds the highest number of known records of the species in the country, occurring mainly in Atlantic Forest remnants. Outside Brazil, *D. hedyotidea* has been recorded in Bolivia, Guyana, and Venezuela, based on collections made between 1905 and 1984 (US 1571809, SP 23845, NY 03144309, NY 03144305, US 2615910, NY 02707924, NY 03144308, US 2170511, NY 03144306, US 2448938, PEL 4457, NY 03144307). These records emphasize the scarcity of collections over nearly eight decades, most of which lack georeferenced data, further hindering understanding of the species' true geographic distribution.

In 1988, the first record from Mato Grosso was documented in a flooded area in the municipality of Cáceres (SJRP 20262). Between 2011 and 2013, additional occurrences were confirmed for the states of Alagoas (UFP 35074, UFP 35073), Bahia (AFR 6321, IBIUEMG 1036), Paraíba (BHCB 209218), and Roraima (UFRR 6345). The present study documents the occurrence of *D. hedyotidea* in Maranhão, in a lowland area where the seasonality of flooding directly influences the local vegetation (Arouche 2021)

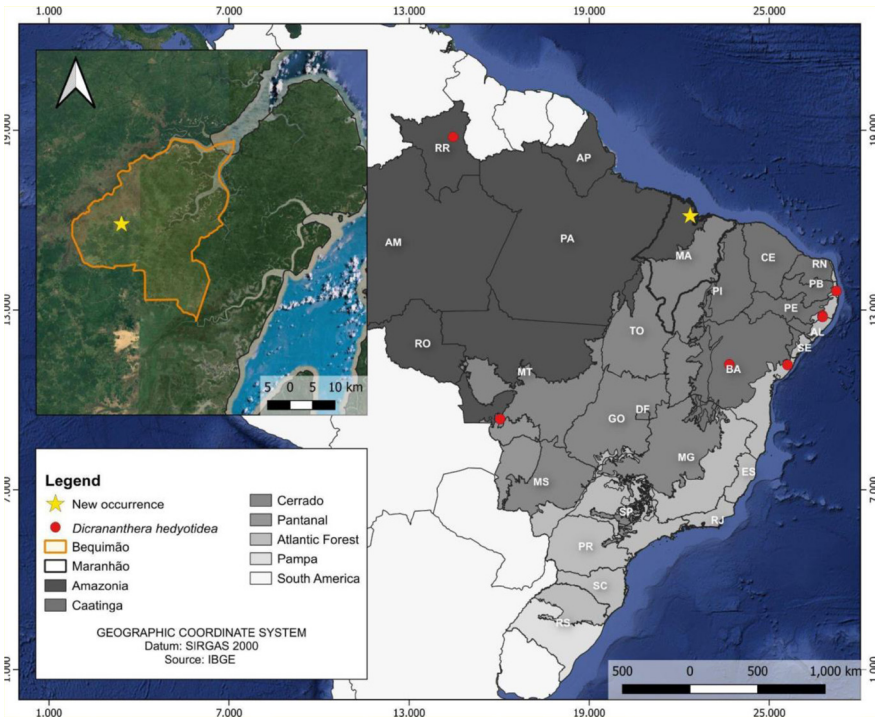


Figure 4. Map showing the geographical distribution of *Dicrananthera hedyotidea* in Brazil, highlighting the new occurrence in Maranhão (yellow star).

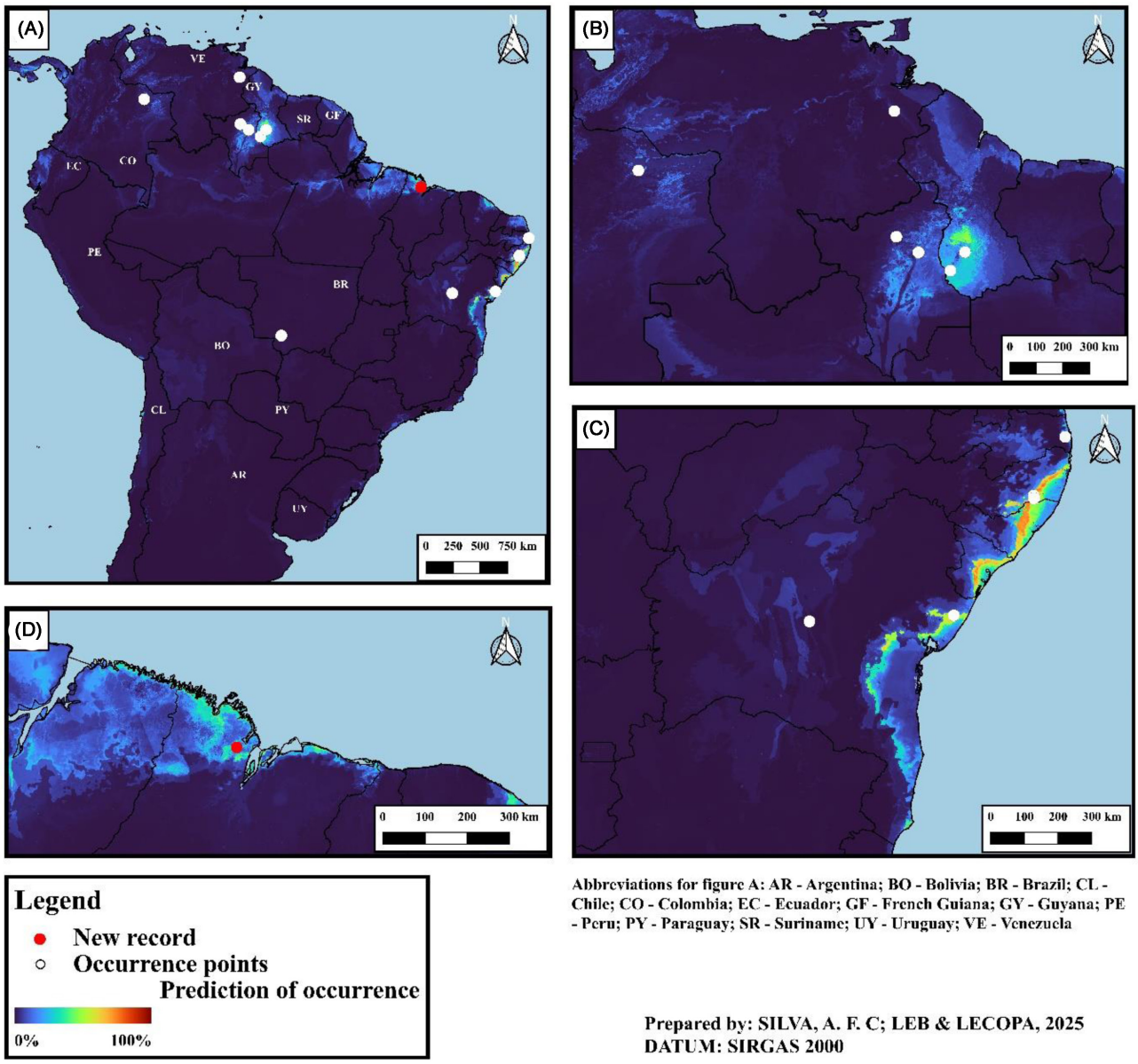


Figure 5. Predictive maps of *Dicrananthera hedyodidea* occurrence in South America, with known distribution points (white dots) and new occurrence (red dot). (A) Overview of occurrence; (B) northwestern portion of South America, highlighting occurrence in Colombia, Venezuela, British Guiana, and Brazil (Roraima); (C) details of potential distribution along the northeastern Brazilian coast; (D) new occurrence for the state of Maranhão, Brazil.

and consequently affects the phenology of annual species such as *D. hedyotidea*.

The ecological niche model produced a coherent spatial prediction of environmentally suitable areas for *D. hedyotidea* across South America (Fig. 5). After filtering multicollinearity, 14 environmental variables were retained and used for model calibration. From the 1000 background points initially generated, 659 were retained after excluding cells with missing environmental data, resulting in a final dataset of 675 observations.

The GBM model showed excellent discriminatory performance, with a training AUC of 0.999 and a cross-validated AUC of 0.789 (± 0.10). The ROC curve (Fig. 6) illustrates the high capacity of the model to discriminate suitable from unsuitable environments, indicating that the selected predictors adequately captured the main ecological constraints of the species.

Variable importance analysis revealed that mean diurnal temperature range (BIO2) was the most influential predictor, contributing 34.53% to the model (Fig. 7). Soil nitrogen content (S02) was the second most influential predictor, explaining 13.43% of the model contribution, followed by precipitation seasonality (BIO15; 11.59%), soil pH (S01; 10.81%), and precipitation of the warmest quarter (BIO18; 6.38%). This

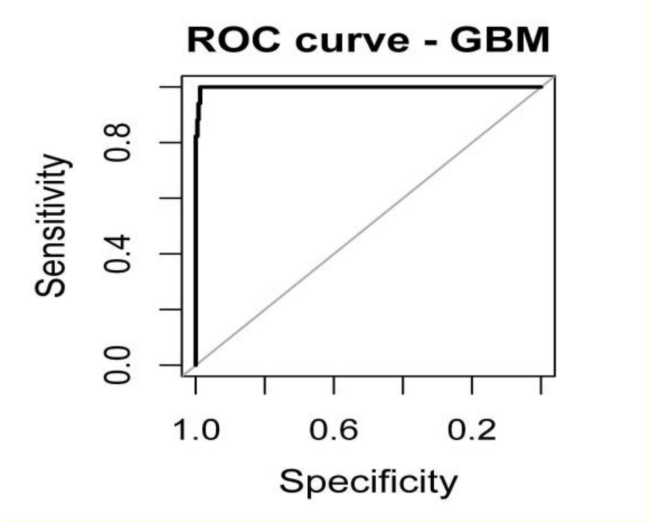


Figure 6. Receiver operating characteristic (ROC) curve of the gradient boosting machine (GBM) model used to predict the potential distribution of *Dicrananthera hedyotidea* in South America. The model showed excellent discrimination capacity, with a training area under the curve (AUC) of 0.999 and a cross-validated AUC of 0.789.

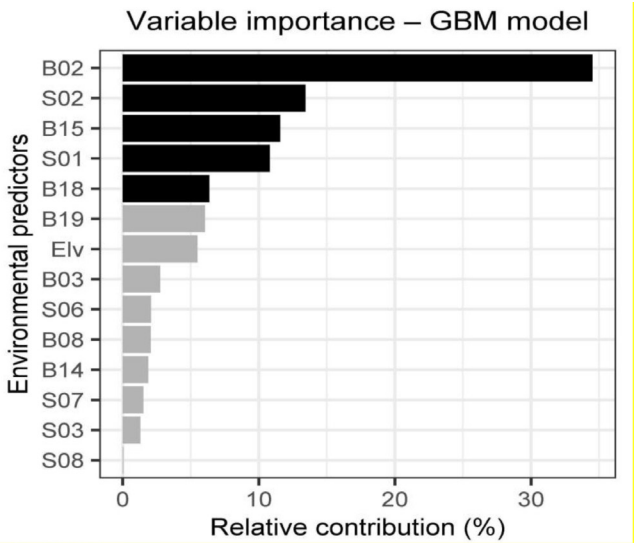


Figure 7. Relative contribution (%) of the environmental predictors retained in the final gradient boosting machine (GBM) model for *Dicrananthera hedyotidea*. Black bars highlight the five most influential variables in the model: mean diurnal temperature range (BIO2), soil nitrogen (S02), precipitation seasonality (BIO15), soil pH (S01), and precipitation of the warmest quarter (BIO18). Grey bars represent predictors with lower relative contributions.

pattern indicates that a small subset of climatic and edaphic variables drives most of the model's explanatory power.

The response curve for BIO2 (Fig. 8) indicates that habitat suitability peaks at intermediate values of daily thermal amplitude, suggesting that *D. hedyotidea* is associated with thermally stable environments. This pattern is consistent with a physiological sensitivity to temperature extremes, as large thermal oscillations may affect germination, photosynthesis, and seedling establishment (Tuomisto et al. 2003, Bendix et al. 2006). Response curves for S02 show a positive relationship between suitability and nitrogen availability, indicating a preference for relatively fertile soils, corroborating evidence that soil nutrient availability plays a key role in structuring tropical plant communities, particularly among Melastomataceae with edaphic specialization (Silveira et al. 2016).

Soil pH (S01) displayed a non-linear response, with higher suitability concentrated in acidic conditions (approximately pH 5.0–5.5). This suggests that *D. hedyotidea* is adapted to acidic substrates, possibly associated with elevated aluminium availability, a trait reported in several Melastomataceae taxa (Watanabe and Osaki 2002). Such edaphic specialization may contribute to the spatial restriction observed in this species. The response curves for BIO15 indicate higher suitability in areas with intermediate to high rainfall seasonality, suggesting that the species is adapted to environments characterized by alternating wet and dry periods, while BIO18 indicates preference for moderate to high rainfall during the hottest months. Together, these climatic responses suggest that *D. hedyotidea* depends on a seasonal water balance that prevents prolonged water stress while maintaining adequate soil moisture for growth and reproduction (Bendix et al. 2006, Brito et al. 2017).

The combined contribution of these variables accounts for more than 75% of the explanatory power of the model (Fig. 7), indicating that *D. hedyotidea* occupies a narrow and environmentally constrained ecological niche. The response curves (Fig. 8) consistently show relatively low tolerance to climatic and edaphic extremes, helping to explain the fragmented and disjunct spatial pattern predicted by the model.

The predicted suitability map (Fig. 5) reveals fragmented areas of high environmental suitability concentrated in the eastern Amazon and along the northeastern Brazilian coast. Importantly, high suitability was predicted for the Baixada Maranhense region, including the municipality of Bequimão, where a new confirmed record was obtained. This spatial pattern suggests that the Maranhão record represents a biogeographically coherent range extension rather than an isolated environmental outlier. The disjunction between Amazonian and Atlantic forest regions may reflect historical climatic oscillations and long-term edaphic heterogeneity, which likely shaped current dispersal limitations and habitat availability. These results indicate that *D. hedyotidea* is environmentally constrained by the interaction between moderate thermal variability, acidic and relatively fertile soils, and seasonally structured rainfall, and that such specialization may render the species particularly sensitive to climate change and land-use transformation, potentially reducing the availability of suitable habitats in the future.

Conclusions

The first record of *D. hedyotidea* for the state of Maranhão underscores the importance of continued taxonomic and floristic studies in this transitional zone of high plant diversity.

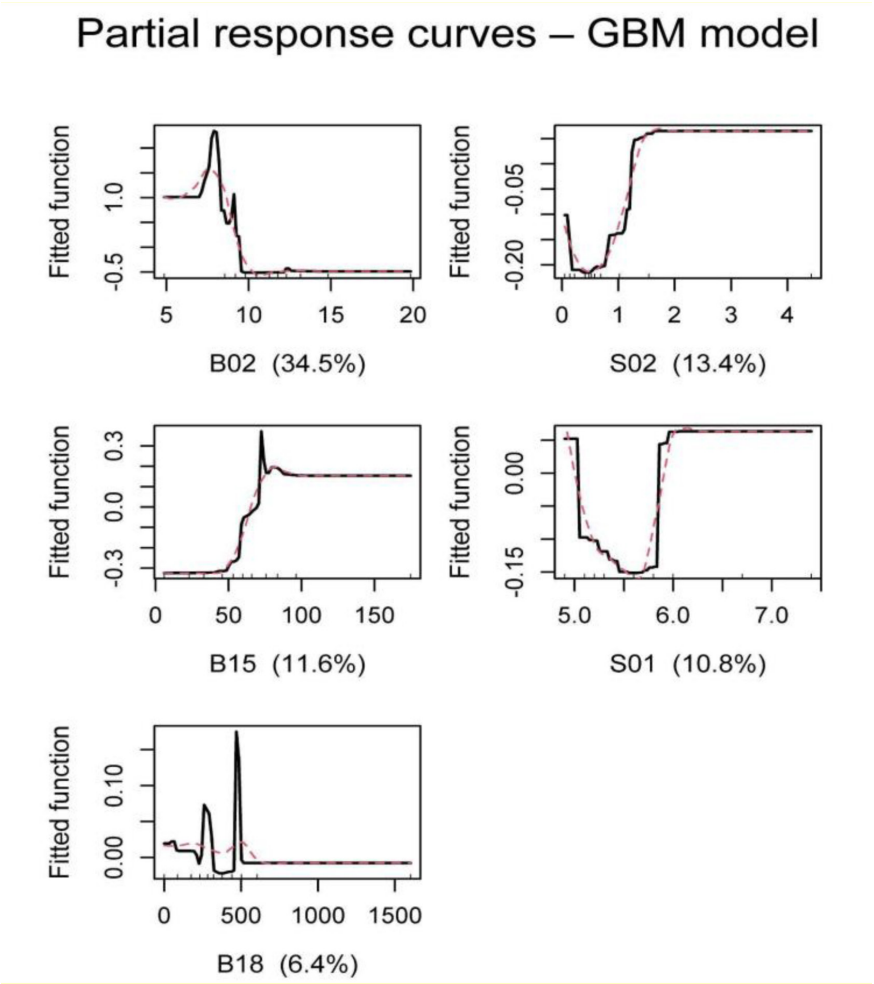


Figure 8. Partial response curves of the five most influential environmental predictors in the gradient boosting machine (GBM) model for *Dicrananthera hedyotidea*. Curves are shown for mean diurnal temperature range (BIO2), soil nitrogen (S02), precipitation seasonality (BIO15), soil pH (S01), and precipitation of the warmest quarter (BIO18). Solid lines represent fitted values, and dashed lines indicate smoothed trends, illustrating species responses while other predictors are held at their mean values.

In this context, further investigations are essential to document the floristic richness of the region and to expand the number of records, not only for the species reported here, but also for other representatives of the tribe Marcetieae across the diverse phytophysiognomies of the state, which still present substantial gaps in botanical knowledge.

The ecological niche modeling presented here provides the first spatial assessment of environmental suitability for *D. hedyotidea* across South America. The species was shown to occupy a narrowly defined ecological niche, primarily shaped by thermal stability, soil fertility, soil acidity, and seasonal precipitation regimes.

The identification of environmentally suitable areas in northeastern Brazil, particularly in the state of Maranhão, supports the interpretation that the newly documented occurrence in Bequimão represents a natural extension of the species' distribution. Instead of being an isolated record, this occurrence fits into a broader pattern of environmentally coherent but spatially fragmented habitats.

The disjunct pattern observed between Amazonian and Atlantic regions is likely the result of long-term climatic fluctuations combined with edaphic specialization and limited dispersal capacity. This ecological specialization suggests that *D. hedyotidea* may be highly sensitive to future climatic shifts and landscape modification.

This new record broadens the understanding of the distribution and occurrence of *D. hedyotidea* in Maranhão, contributing to the overall knowledge of the state's biodiversity and emphasizing the species diversity of the Baixada Maranhense ecosystem. Moreover, it provides a basis for future research and the development of conservation strategies within the environmental protection areas of Maranhão. Our results highlight the importance of combining herbarium-based records with ecological niche modeling as a tool to guide future botanical surveys, refine biogeographical hypotheses, and support conservation planning for narrowly distributed tropical plant species.

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Conflict of interest – The authors declare no conflict of interest.

Author contributions

Elias Julio Oliveira Correa: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Methodology (equal); Project administration (equal); Writing – original draft (equal). **Sandro Márcio dos Santos Junior**: Data curation (equal); Writing – original draft (equal). **Antônio Fernando Costa da Silva**: Data curation (equal); Methodology (equal); Writing – original draft (equal). **Kalynne Nayara Lima dos Santos**: Data curation (equal); Methodology (equal); Writing – original draft (equal). **Eduardo Bezerra de Almeida Jr**: Conceptualization (equal); Funding acquisition (equal); Project administration (equal); Writing – review and editing (equal).

Data availability statement

Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.0rxwdbsg1 (Correa et al. 2026).

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