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Scientific Article

Data analysis of *Melocactus* (Cactaceae) virtual herbarium in the Caatinga biome: a synthesis of reproduction and geographical distribution

Análise de dados virtuais de herbário sobre *Melocactus* (Cactaceae) na Caatinga: uma síntese reprodutiva e de distribuição geográfica

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ABSTRACT - The objective of this study was to analyze data of the genus *Melocactus* (Cactaceae) in the Caatinga biome using a virtual herbarium, determine its reproductive aspects, and establish its geographical distribution. Data were collected from the SpeciesLink platform. Notes on exsiccata labels were analyzed to assess reproductive characteristics. Coordinate information was used to develop a distribution map for the genus in the Caatinga biome. A total of 469 records were found in 35 herbaria in Brazil. *Melocactus zehntneri* stood out with 208 records, followed by *M. ernestii*, and *M. bahiensis*. The data were concentrated in a few herbaria, mainly in the Herbarium of the State University of Feira de Santana, which had 28% of the records. Collections were carried out in June (63 records) and in July (59 records). Regarding the reproductive period, *Melocactus* was active throughout the year, but more concentrated from June to October. The genus is composed of species that depend on animal pollination and dispersal, according to coloration and visitation data. *Melocactus* is widely distributed throughout the Caatinga, with a tendency to concentrated in drier areas of the biome, in the states of Bahia, Pernambuco, and Paraiba. Herbaria are valuable tools for ecological investigations; therefore, promoting the digitalization of collections and improving the quality and quantity of annotations on specimens are necessary. The genus *Melocactus* has several characteristics that make it an essential group for maintaining biodiversity in the Caatinga biome.

Keywords: Pollination. Reproductive phenology. Exsiccata.

RESUMO - O objetivo do estudo foi analisar os dados do gênero *Melocactus* (Caatinga) na Caatinga em herbário virtual e avaliar seus aspectos reprodutivos e estabelecer a sua distribuição geográfica. Para tanto, foram coletadas informações na plataforma *SpeciesLink*. As exsicatas foram analisadas quanto às notas em suas etiquetas para a avaliação dos aspectos reprodutivos. A partir das informações das coordenadas, foi elaborado um mapa da distribuição do gênero ao longo da Caatinga. Um total de 469 registros foram encontrados em 35 herbários brasileiros. *Melocactus zehntneri* se destacou com 208 registros, seguido por *M. ernestii*, e *M. bahiensis*. Os dados estiveram concentrados em poucos herbários, com destaque ao HUEFS, que liderou com 28% dos registros. Verificou-se 63 registros nos meses de junho e 59 em julho, referentes à quantidade de coletas realizada por mês. Em período reprodutivo *Melocactus* foi ativo ao longo do ano inteiro, porém com concentração de junho a outubro. O gênero é composto por espécies que dependem da polinização e da dispersão realizada por animais, de acordo com os dados de coloração e de visitação. *Melocactus* é amplamente distribuído pela Caatinga, com tendência de concentração em áreas mais secas dentro do bioma, nos estados da Bahia, Pernambuco e Paraíba. Os herbários são ferramentas valiosas para investigações ecológicas, portanto é necessário promover a digitalização dos acervos, bem como melhorar a qualidade e quantidade das anotações sobre os espécimes. O gênero *Melocactus* apresenta diversas características que o torna um grupo essencial para a manutenção da biodiversidade da Caatinga.

Palavras-chave: Polinização. Fenologia reprodutiva. Exsicata.

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INTRODUCTION

The family Cactaceae has 81 genera in Brazil, and 15 of them are endemic (ZAPPI; TAYLOR, 2023). The genus *Melocactus* Link & Otto stands out with 32 species, 22 of them endemic to Brazil (ZAPPI; TAYLOR, 2023). The morphology of these cacti is tubercular, ribbed with central and radial spines, a terminal cephalium where flowers are produced, and fruits (ZAPPI; TAYLOR, 2023). Their flowers are tubular, with vibrant colors, and exhibit syndrome of ornithophilous and lepidopterous pollination, with conical and fleshy fruits dispersed by lizards and ants (GOMES, QUIRINO; MACHADO, 2014). According to Quirino and Machado (2014), the Caatinga fauna is closely related to the family Cactaceae, and especially to the genus *Melocactus*, which maintains continuous flowering throughout the year, providing resources for pollinators and dispersers.

Melocactus species have economic, ecological, and cultural value; they can be used as ornamentals, forage, food, mystical or religious items, rain bioindicators, and in human and animal medicine (SILVA, 2015). Considering their importance, studies on their reproductive biology, floral phenology, biotic interactions, and geographical distribution are needed (BRAVO FILHO, 2018). Globular cacti of the genus *Melocactus* occur from the northeast of Minas Gerais state to the Brejos de Altitude region in the states of Pernambuco and Paraiba, on gneissic inselbergs and crystalline and arenitic rocks surrounded by a matrix of Caatinga arboreal species, predominantly composed of xerophytic vegetation.

Melocactus populations are susceptible to habitat destruction caused by anthropogenic activities and predatory extraction of natural resources due to the ornamental potential of these Cactaceae species (CARDOSO et al., 2018).

The availability of consistent and updated data on the geographical distribution of species, associated with their biotic characteristics, is one of the priorities highlighted by biodiversity conservation agencies and researchers. The number of studies focused on plant distribution patterns, including endemic and threatened species, is progressively increasing (CANO-ORTIZ et al., 2016; RIBEIRO-SILVA et al., 2016; SANTOS; HASSEMER; MEIADO, 2018). This emphasizes the importance of understanding spatial patterns and ecology of populations for species conservation. However, this is still lacking for Cactaceae species.

In recent years, herbarium data has been seen not only as material for taxonomic research, but also as a contribution of essential information for different investigations, such as phenological and morphological analyses, geographical distribution of species, and biodiversity conservation (HEBERLING; PRATHER; TONSOR, 2019). Descriptions of exsiccatae have documentary and historical aspects and, therefore, are essential for understanding past environments and analyzing changes over time and space, as well as assessing changes in biodiversity caused by anthropogenic activities and obtaining evidence on climate change and its effects on the ecology of species (HEBERLING; PRATHER; TONSOR, 2019; LIMA et al., 2021). The digital revolution and the possibility of digitalizing herbarium collections have promoted a new era of research. However, many issues are still under-explored, including the overall landscape of information on exsiccatae and how they can be used to address different ecological questions, as well as the spatialization of these records, providing a broad understanding of the distribution of species, especially some ecologically important groups in the Caatinga biome.

In this context, the objective of this study was to analyze data on the genus *Melocactus* (Cactaceae) in the Caatinga biome using a virtual herbarium to assess reproductive aspects of the genus by categorizing data on flowers and fruits, its reproductive phenology, and pollination and seed dispersal syndromes; additionally, the study aimed to provide a spatialization of records and establish the geographical distribution of the genus.

MATERIAL AND METHODS

Study area

The Caatinga biome has an area of 912,529 km^2, corresponding to 10,7% of the Brazilian territory (SILVA et al., 2017). This biome consists of dry forests and is present in the states Minas Gerais, Sergipe, Alagoas, Pernambuco, Piaui, Ceara, Paraiba, and Rio Grande do Norte, within the Semiarid region in the Northeast of Brazil. However, its large area results in a highly heterogeneous environment, encompassing floristic elements from different biomes, such as species of humid tropical forests on the top of mountain ranges, with rainfall depths higher than neighboring areas, forming the so-called Brejos de Altitude (Highland Swamps), as well as species of Cerrado biome and Campos Rupestres (Rupestrian or Rocky Fields) (QUEIROZ et al., 2017). Caatinga has a representative endemic flora with high beta diversity due to its complex environmental characteristics, mainly due to the edaphic conditions, responsible for the formation of different floristic compositions between areas of Sedimentary Caatinga, characterized by sandy, deep, and poorly fertile soils, with shrubs and small trees, and Crystalline Caatinga, which has shallow and fertile soils, usually with rocky outcrops, providing a favorable substrate for the establishment of several Cactaceae species (QUEIROZ et al., 2017; FERNANDES; QUEIROZ, 2018).

Data collection

Data were collected from the SpeciesLink platform (<https://specieslink.net>) for the period from 1990 to 2021, totaling a 32-year period of records, covering the entire territory of the Caatinga biome.

The species were filtered by scientific name including *Melocactus*. The search option on the website redirects to a page containing only the records linked to the genus of interest. A filter by species name was chosen to better organize the collected data.

The names of the records in SpeciesLink are highlighted with different colors; records with official names are shown in green, while synonyms are shown in gray. Records catalogued only to the genus level are shown in blue, and names that were not found are shown in orange. Therefore, records that contained erroneous or outdated names were corrected and updated according to the website <https://floradobrasil.jbrj.gov.br>.

The following data from exsiccatae in the search results were collected: species and subspecies; state and municipality where it was collected; geographic coordinates, month, and year of collection; collector's name; herbarium; visitors found; habit; substrate; fruit and flower colors; pollination and dispersal syndromes; fruit and flower phenology; flower and fruit sizes; anthesis; and floral visitors.

Mapping of records

Information on the geographic coordinates (X and Y) of each exsiccata was collected to generate a vector file with representative points, which was opened in the QGis 3.22.6 program to develop maps of record locations.

The location map obtained from the general exsiccatae search was clipped using the Caatinga shapefile available on the website <https://www.ibge.gov.br> as a mask layer to select only points within the biome boundaries. Thus, all records outside the Caatinga biome boundaries were excluded from the dataset.

Data analysis

The Pantone color palette (available at: https://www.pantone.com.br/) was used to categorize flower and fruit colors. The classification for the closest color in the palette was based on the color described by the collector; for example, records described as "dark pink" were classified as "magenta". These processes aimed to approximate the colors described due to the lack of standardization of the terms used for the different exsiccatae. The following color categories were used for classification: magenta, pink, purple, and lilac for flowers; and white, lilac, pink, magenta, and red for fruits.

Annotations provided by the collector, whenever available, in each specimen were used for classifying the habits of the collected exsiccatae.

The difference in the number of exsiccatae collections among three decades (1990-1999, 2000-2009, and 2010-2019) was analyzed using the Kruskal-Wallis test; 2020 and 2021 were removed from the analysis due to the pandemic's effect on the number of collections.

The reproductive period was evaluated by a circular analysis of the data from the collection records of the exsiccatae that showed flowering and/or fruiting, using the program Oriana. The uniformity of the data distribution was analyzed using the Rayleigh test, whereas the data concentration was analyzed based on the length of the mean vector *r* (MORELLATO; ALBERTI; HUDSON, 2010).

RESULTS AND DISCUSSION

A total of 469 exsiccatae were recorded, distributed in 35 herbaria, representing 18 species and 6 subspecies; 22 of them are endemic to Brazil. Only 20 of the total exsiccatae were identified to the genus level. The species *Melocactus zehntneri* was the most significant (208 records), followed by *M. ernestii* and *M. bahiensis* (91 and 37 records, respectively) (Table 1). These findings emphasize the importance of eastern Brazil as a center of diversity for the genus *Melocactus*, with emphasis on the Caatinga biome, which comprises approximately 55% of the richness of this genus in Brazil, according to current data from the Flora e Funga do Brasil (2024) (continuously updated). However, human activity has caused impacts in a large part of the Caatinga (SILVA; BARBOSA, 2017), and the rapid advancement of these environmental changes has imposed high risks for slow-growing species, such as those of the genus *Melocactus* (LAFITE; SALIMON, 2020). Several species of this genus that are endemic to Brazil have shown a population decline and are under different levels of threat, according to the IUCN (2024). Therefore, the importance of the Caatinga biome grows as knowledge about it increases, as this biome has a unique but fragile richness, requiring increasing attention in terms of environmental conservation and protection of its biodiversity.

Table 1. Total number of exsiccates for each of the 24 *Melocactus* species and the states where they were collected, from 1990 to 2021 in the Caatinga biome. AL = Alagoas, BA= Bahia, CE = Ceará, MG = Minas Gerais, PE = Pernambuco, PI = Piauí, PB = Paraíba, RN = Rio Grande do Norte, SE = Sergipe.

Species	Number of exsiccates	States
Melocactus Link & Otto	20	PE, CE, BA, PB, AL
Melocactus albicephalus Buining & Brederoo	2	BA
Melocactus azureus Buining & Brederoo*	5	BA
Melocactus bahiensis (Britton & Rose) Luetzelb.*	37	PE, PB, BA, AL, CE, SE, RN
Melocactus bahiensis subsp. *bahiensis* (Britton & Rose) Luetzelb*	8	PE, BA, AL,
Melocactus concinnus Buining & Brederoo*	14	BA, MG, PE
Melocactus deinacanthus Buining & Brederoo*	2	BA
Melocactus ernestii Vaupel*	91	PB, AL, PE, BA, MG, SE
Melocactus ferreophilus Buining & Brederoo*	1	BA
Melocactus glaucescens Buining & Brederoo*	13	BA
Melocactus horridus Werderm.	5	PE
Melocactus inconcinnus Buining & Brederoo*	2	BA
Melocactus lanssensianus Buining & Brederoo*	1	PB
Melocactus levitestatus Buining & Brederoo*	2	MG, BA
Melocactus oreas subsp. *cremnophilus* (Buining & Brederoo) P.J.Braun.*	6	BA
Melocactus oreas subsp. *oreas* Miq.*	5	BA
Melocactus pachyacanthus Buining & Brederoo*	5	BA
Melocactus pachyacanthus subsp. *viridis* N.P.Taylor*	2	BA
Melocactus paucispinus Heimen & R.J.Paul*	10	BA
Melocactus salvadorensis Werderm*	14	BA
Melocactus sergipensis N.P.Taylor & M.V.Meiado*	2	SE
Melocactus violaceus Pfeiff*	7	SE, BA, CE, RN
Melocactus violaceus subsp. *margaritaceus* N.P.Taylor*	3	SE, PE
Melocactus violaceus subsp. *ritteri* N.P.Taylor*	4	BA
Melocactus zehntneri (Britton & Rose) Luetzelb*	208	BA, PE, CE, PI, PB, RN, SE, AL, SE

*endemic species, according to Flora e Funga do Brasil (2024) (continuously updated).

Herbaria

Exsiccatae were found in 35 herbaria, with the Herbarium of the State University of Feira de Santana (HUEFS) standing out with 28% (130 records) over the 32 years analyzed. The second most significant was the Geraldo Mariz Herbarium of the Federal University of Pernambuco, with 12% (57 records), followed by the BHCB Herbarium - Fanerogamas Herbarium of the Federal University of Minas Gerais, with 7% (34 records). The remaining 58% are distributed among the other 32 herbaria found in this study. The state with the highest number of collections was Bahia (182 records), followed by Pernambuco (117) and Paraiba (81) (Figure 1). In general, herbaria are academic units, representing an asset for several higher education institutions throughout the country, usually associated with departments involved with biodiversity research in Brazil; therefore, a large part of their records result from collections conducted during scientific research. Thus, differences in the intensity of academic research among study centers may influence the number of plant specimens and the size of the herbarium's collection. Consequently, some regions showed concentrations of collection records, whereas others showed a dispersion of collections, forming a data set with some spatial bias on a regional scale (DARU et al., 2018). This can be exemplified by the *Melocactus* collection of the HUEFS, which consists of 71% records carried out in Bahia. This dependence leaves gaps in the documentation of the genus in a large part of the Caatinga biome. Funding for research programs and the regional development are essential to fill these gaps and to expand the general knowledge of the biome's flora.

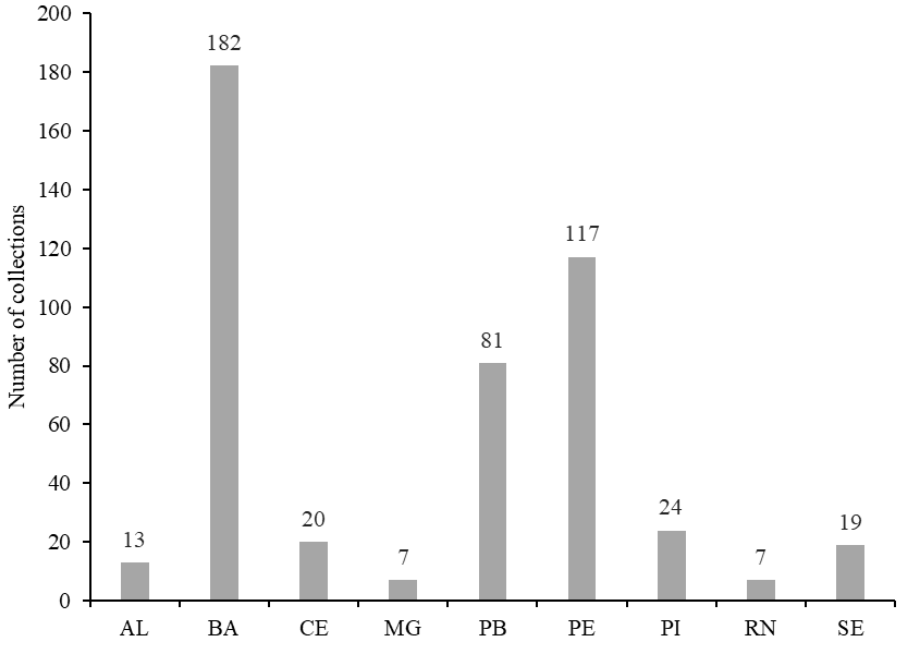

Figure 1. Number of collections recorded for *Melocactus* from 1990 to 2021 in the Caatinga by state. AL = Alagoas, BA= Bahia, CE = Ceará, MG = Minas Gerais, PE = Pernambuco, PI = Piauí, PB = Paraíba, RN = Rio Grande do Norte, SE = Sergipe.

According to the Kruskal-Wallis test, no significant differences were found in the number of collections among the three decades analyzed ($p = 0.2273$; $H = 2.95$) (Figure 2), although a slight trend of increase was found for the 2000-2009 decade followed by a decrease. Considering the significant number of underrepresented herbaria, this genus is still poorly documented in several regions, therefore, denoting an expectation of an increasing rate in collections. However, the pattern found over the last decade analyzed may resulted from the different economic situations that Brazil has experienced in the last years, as periods of economic growth resulted in greater investments in several research institutions, consequently increasing the documentation of the Brazilian biodiversity. On the other hand, the economic setbacks in the last decade and successive cuts in investments in science have contributed to the number of collections decreasing to the level of 30 years ago. Considering that this study analyzed collection trends for only one genus, it is not possible to determine the extent of the observed pattern for botanical collections in general, requiring broader investigations to confirm whether the pattern is generalized and, subsequently, determine the overall impact of the economic recession on both the advancement of knowledge of the Brazilian flora and the growth of botanical collections of regional herbaria.

The highest number of collections were found for June (63 records), October (60 records), and July (59 records). The temporal distribution of collections concentrated in some months denotes a temporal bias in the sampling, probably connected to the reproductive season of the species (DARU et al., 2018). This is because annotations on floral and fruit characteristics are frequent in the assembly of exsiccatae and are often necessary for plant identification, therefore, essential at the time of collection. The most significant problem resulting from this bias may be the absence of data on species at vegetative stage. Although *Melocactus* species do not have leaves, easily acquired information, such as diameter and height, can significantly contribute to conclusions about plant populations.

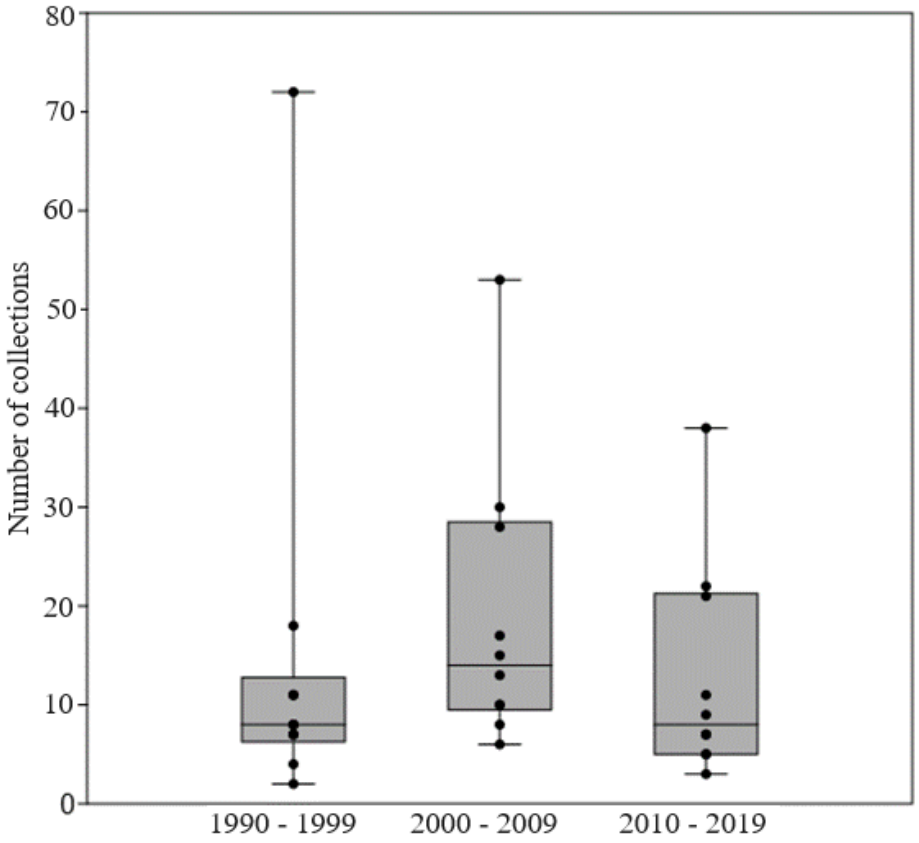

Figure 2. Comparison of the number of collections for *Melocactus* in the Caatinga over three decades (1990-1999; 2000-2009 and 2010-2019).

Similarly, habit types were identified in only 4% of the records (n = 22). Additionally, essential information about the environment where specimens were collected was not often found; for example, substrate types were described for 126 exsiccatae, corresponding to only 26.8% of the total records collected. Digitization tends to make herbaria globally integrated (DAVIS, 2023), forming a rich database for research and analyses. Therefore, the continuous improvement of quantity, quality, and comprehensiveness of data is essential for this process.

Reproduction

The data analysis showed that 255 exsiccatae (54.3%) were in flowering and fruiting, which was considered the reproductive period. More detailed information for each taxon began to progress in 1998, probably due to the increasing availability of resources for field studies and a growing production of taxonomic collections (HEBERLING; PRATHER; TONSOR, 2019).

Description of flower color was found in 46% of the records (n = 216), and pink flowers were the most common, described in 149 exsiccatae, followed by magenta flowers (n = 58) (Figure 3). Regarding fruit color information (n = 93, 19%), the most frequent descriptions were pink and magenta fruits (Figure 4). The pattern of flower and fruit coloration found for *Melocactus* species is predominantly bright colors, which are related to pollination and biotic dispersal syndromes, such as ornithophily, psychophily, melitophily, and saurophily for pollination and saurocoria for seed dispersal (GOMES; QUIRINO; MACHADO, 2014). Species of this genus are completely dependent on animals to complete their life cycles, indicating their significant importance for providing resources to the local fauna (QUIRINO; MACHADO, 2014), thus ensuring the maintenance of several ecosystem processes in the Caatinga biome.

The analyzed herbarium data showed information about visitors, which were distributed in the following pollinator groups: hummingbirds (25 records) and hummingbirds and lepidopterans (n = 13), with information that they made legitimate visits to the flowers. These findings show the degree of generality of this relationship for the genus, which is consistent with information found in other studies that have reported pollination by hummingbirds, butterflies, and lizards for plants in the Caatinga biome (GOMES; QUIRINO; MACHADO, 2014; GOMES et al., 2016). The anthesis time, other information of floral biology, was rarely found in the total records (n = 18; 3%), with occurrence always in the afternoon, approximately at 14:30 h, classified as diurnal and vespertine, serving as a complement to the determination of the pollination syndrome.

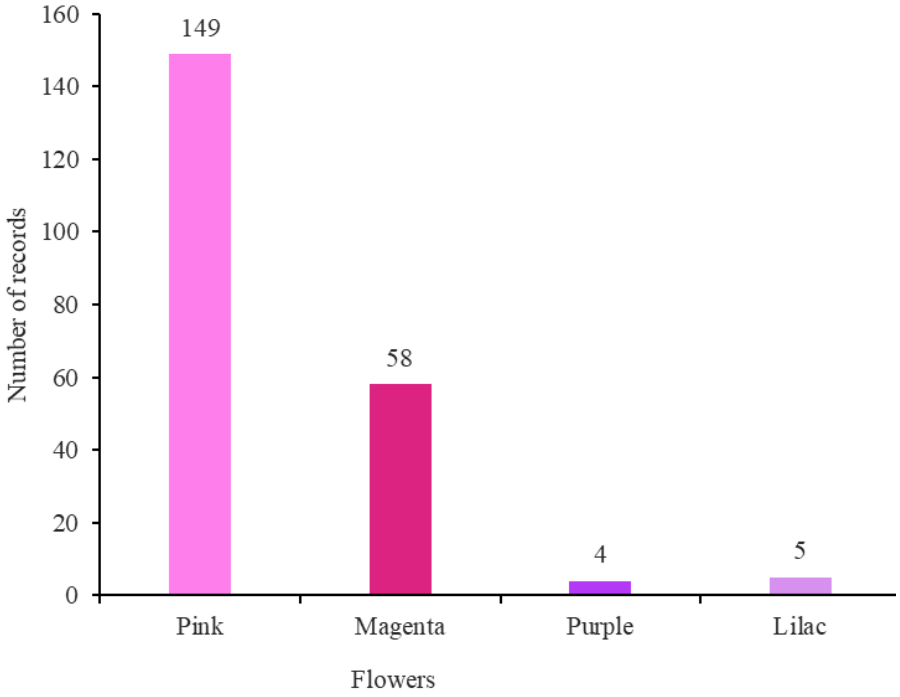

Figure 3. Flower colour pattern observed in *Melocactus* specimens found in the Caatinga, based on virtual herbarium data from 1990 to 2021.

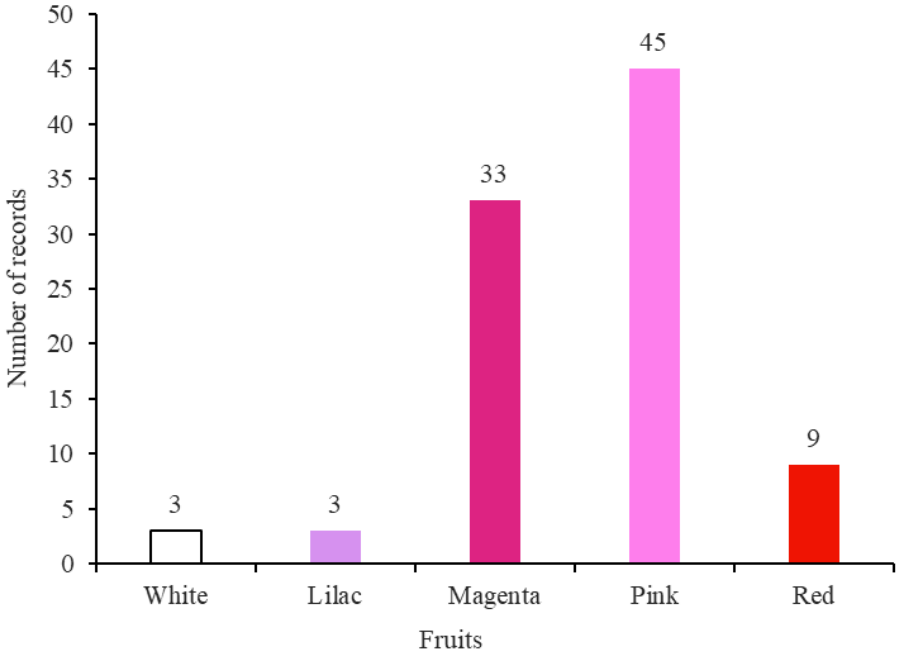

Figure 4. Fruit colour pattern observed in *Melocactus* specimens found in the Caatinga, based on virtual herbarium data from 1990 to 2021.

Regarding dispersers, lizard species were the most observed (n = 14). Some studies have reported the presence of lizards interacting with flowers and fruits, forming a double mutualism (pollinator and disperser) for some species of the genus (GOMES; QUIRINO; MACHADO, 2014; GOMES et al. 2021). Lizards seem to establish a very close relationship with species of the family Cactaceae in the Caatinga biome, benefiting from an efficient acquisition of resources, as they use a variety of foods provided by these plant species (GOMES et al., 2016). Additionally, one record of ants was found. Although infrequent, ants visiting fruits from *Melocactus* species have been reported by Gomes et al. (2016).

The distribution of the data was not uniform, according to the Rayleigh test (p-value = 0.007). The length of the vector r indicated a low concentration of the reproductive period (r =

0.142), with the mean group indicating the month of August (Figure 5). tests performed denote reproductive processes of *Melocactus* species distributed throughout the year, with a tendency for greater activity from June to October. Similarly, Bezerra-Silva et al. (2024) found a year-round reproductive activity they had a year-round reproductive period for the genus *Xiquexique* (Cactaceae) based on herbarium data, however, differing from *Melocactus* in the months of greatest concentration of phenophases. This indicates a temporal segregation in the genera in terms of reproductive time, favoring the availability of resources to the fauna during different periods of the year. The results of this study provide an overview of the reproductive phenology of the genus *Melocactus*, however, different reproductive patterns of the species throughout the year should be considered, as each species may have a distinct reproductive period (HORA; MEIADO, 2022). Accessing the phenology of each individual species was not possible due to the low number of collections for many of them. A greater sampling effort, incorporating data from physical herbaria and field studies, may be essential for an understanding of the reproductive cycles of the species and for the implementation of conservation strategies according to the specific demands of each reproductive phenophase.

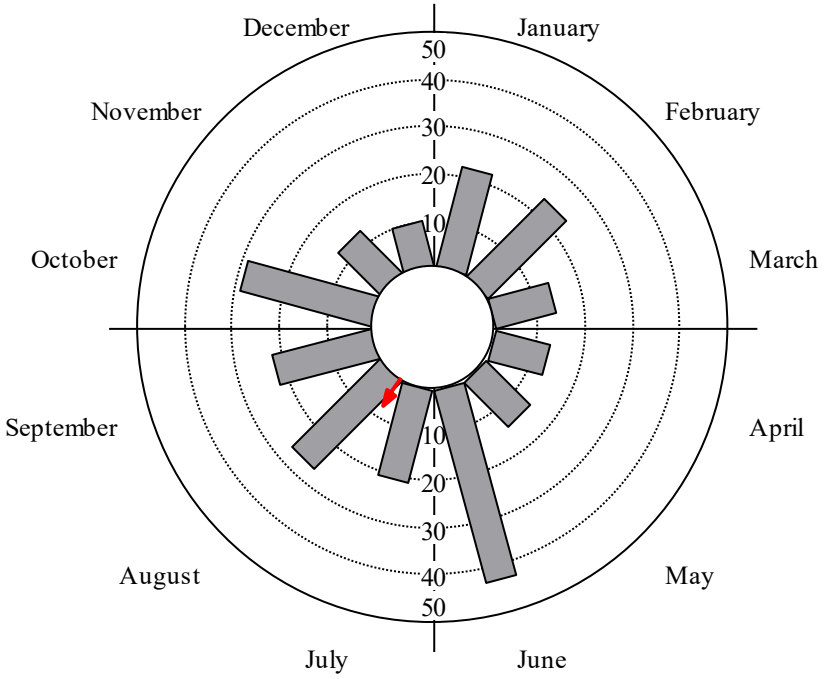

Figure 5. Circular diagram representing the reproductive period (flowering and fruiting) of the genus *Melocactus* (Cactaceae) in the Caatinga based on virtual herbarium data from 1990 to 2021.

Geographical distribution of records

Plotting the data on the collection locations of *Melocactus* species allowed for the georeferencing of 469 points (Figure 6). This genus has a wide distribution in the Caatinga, however, with a tendency to concentrate in the eastern portion of the biome, forming a diagonal that extends from the states of Paraíba to Bahia, corresponding to the areas with less rainfall within the Caatinga (ANDRADE et al., 2017). These areas may become even more arid due to climate change, limiting the distribution of many species in these environments, especially endemic cacti (SIMÕES et. al., 2020). These findings may be the first to show the distribution of *Melocactus* species in the Caatinga biome since the seminal study of Taylor (1991); the extent of the genus to the north of Pernambuco and to the west of Piaui are among these updates. The spatialization of exsiccatae records implies spatial biases involved in the collection of materials, such as the tendency of abundant collections along roadsides and in other easily accessible locations. (DARU et. al., 2018). Consequently, the distribution of some species may not yet be fully observed through virtual herbarium data. Two main strategies should be considered to overcome this problem: boosting the digitization of local herbarium collections, which may contain a high richness but are not easily accessible; and promoting expeditions to remote areas or less-visited locations. However, overall, the distribution presented in this study represents an excellent picture of how the genus *Melocactus* is distributed in the Caatinga biome.

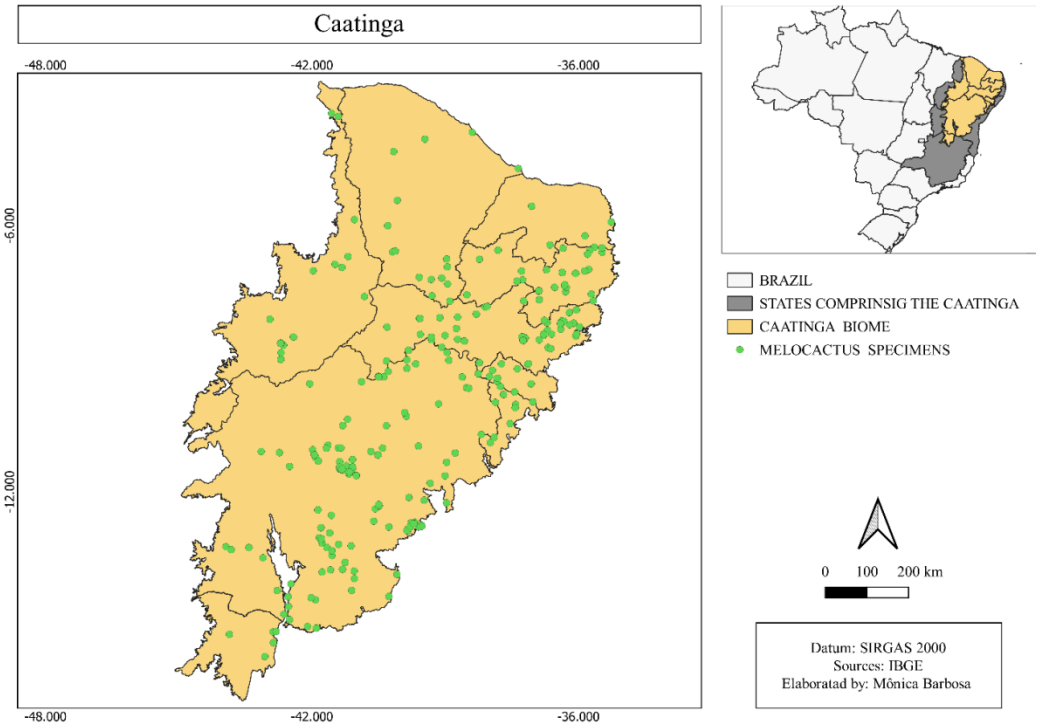

Figure 6. Distribution of the genus *Melocactus* (Cactaceae) in the Caatinga based on virtual herbarium data from 1990-2021.

CONCLUSION

The analysis of *Melocactus* (Cactaceae) database contained in the SpeciesLink platform for the 1990-2021 period revealed a high concentration of records of *Melocactus* species in the Caatinga biome, Brazil, in a few herbaria, with abundant collections in only three states (Bahia, Pernambuco, and Paraiba), which can be attributed to the number of herbaria and researchers in each of these states. Most of the of the exsiccatae have annotations of reproductive characteristics, while descriptions of vegetative characteristics and collection environment aspects are infrequent. Virtual herbaria can be increasingly important tools for ecological research; however, they depend on more detailed documentation during collections, which can drive the development of new standards for exsiccatae production.

Species of the genus *Melocactus* depend predominantly on animals for pollination and seed dispersal, as shown by the pattern of bright colors of their flowers and fruits and by the records of visitors in the exsiccatae. Additionally, their reproductive period occurs throughout the year, with a higher concentration between June and October. The relationships with pollinators and dispersers and the temporal organization of the phenophases found reinforce the importance of this genus for the maintenance of the fauna in the Caatinga by providing resources both in the rainy and dry seasons; therefore, these species are essential for the conservation of biodiversity in this biome.

The geographical distribution of the genus is wide, occurring throughout the Caatinga biome, however, with a higher abundance of records for Bahia, Pernambuco, and Paraiba, mainly in the regions of lower rainfall depths. The smaller number of records found for the states of Piaui, Ceara, Rio Grande do Norte, Alagoas, and Minas Gerais indicates a need to intensify the number of collections of *Melocactus* species across these states; in terms of soil and rainfall, they have similar phytogeographic regions to those with the highest records of *Melocactus* species.

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