EX SITU CONSERVATION IN THE BRAZILIAN SEMIARID: CACTACEAE HOUSED IN THE COLLECTION OF THE GUIMARÃES DUQUE CACTARIUM

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Ex situ conservation in the Brazilian semiarid: Cactaceae housed in the collection of the Guimarães Duque Cactarium

Conservação *ex situ* no Semiárido brasileiro: Cactaceae da coleção do Cactário Guimarães Duque

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ABSTRACT
Nearly 1/3 of all cacti species in the world are at risk of extinction because of human impacts. In Brazil, Cactaceae is among the 10 most endangered families of national flora, making conservation measures essential for this family. In this paper, we document the species preserved in the *ex situ* collection at the Guimarães Duque Cactarium (CAGD) located in the National Institute of Semiarid, Paraíba state, Brazil. The collection consists of 158 species and 1013 specimens, including mostly Cactaceae and succulent representatives of eight other botanical families. The cacti collection covers 952 specimens belonging to 123 species and 36 genera. Of this total, 104 species are native to Brazil and 19 are exotic species from nine countries. The CAGD collection includes representatives from several phytogeographic domains of the country, highlighting endemic and threatened cacti species occurring in the Caatinga. 70% (N = 83) of the cacti species recorded in the Brazilian Semiarid region are represented in the CAGD collection. Furthermore, in the collection, there are cacti species classified with different threat categories (Near threatened, Vulnerable, Endangered and Critically endangered), with 21 species classified according to MMA/2014 list and 35 species according to

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IUCN Red List. We also discuss the main challenges and perspectives of the cactarium supporting *ex situ* conservation actions for Cactaceae.

Keywords: Caatinga, Cacti, Conservation support, Succulents, Threatened species.

RESUMO

Aproximadamente 1/3 de todas as espécies de cactos do mundo estão em risco de extinção como consequência dos impactos humanos. No Brasil, Cactaceae é uma das 10 famílias mais ameaçadas da flora nacional. Esse cenário alerta para a necessidade de apoio à conservação da família. Neste artigo, documentamos as amostras de cactos preservadas na coleção *ex situ* do Cactário Guimarães Duque (CAGD), localizada no Instituto Nacional do Semiárido, Paraíba, Brasil. A coleção é composta por 158 espécies e 1013 espécimes, incluindo Cactaceae e plantas suculentas de outras oito famílias botânicas. A coleção de cactos consiste em 952 espécimes pertencentes a 123 espécies e 36 gêneros. Desse total 104 espécies são cactos nativos do Brasil e 19 são espécies exóticas provenientes de nove países diferentes. A coleção abrange representantes dos diferentes domínios fitogeográficos do país, com destaque para espécies endêmicas e ameaçadas que ocorrem na Caatinga. 70% (N = 83) das espécies de cactos registradas no Semiárido estão representadas no acervo do cactário. Ademais, a coleção do cactário possui 21 e 35 espécies em diferentes categorias de ameaça (Quase ameaçada, Vulnerável, Ameaçada e Criticamente ameaçada) de acordo com a portaria do MMA/2014 e Lista Vermelha da IUCN, respectivamente. Finalizamos este levantamento discutindo os principais desafios e perspectivas do Cactário em apoio a ações de conservação *ex situ* para Cactaceae.

Palavras-chave: Caatinga, Cactos, Apoio à conservação, Suculentas, Espécies ameaçadas.

1 INTRODUCTION

Cactaceae Juss. is one of the most diverse plant families in the Neotropics, with 100 genera and 1850 recognized species (Hunt *et al.* 2006; Nyffeler & Eggli 2010). In general, cacti are important floristic elements of arid and semiarid environments with extreme conditions (Mutke 2015). These plants have been able to succeed in these environments through a variety of morphological, physiological and ecological adaptations (Nobel 2002). Additionally, the centers of diversity and distribution of cacti are in arid and semiarid regions of the American continent, mainly in the Mexican deserts, Andes, and eastern Brazil (Hunt *et al.* 2006; Taylor & Zappi 2004).

Currently, there are 273 cacti species recorded for Brazil, distributed among 39 genera (Zappi & Taylor 2020) with specimens in all phytogeographic domains of the country: Caatinga, Cerrado, Atlantic Forest, Amazon, Pampa and Pantanal (Zappi *et al.* 2011). An estimated 70% of these species are endemic, with 14 genera found exclusively in the Brazilian territory (Zappi & Taylor 2020). In the Brazilian Semiarid region, whose predominant biome is the Caatinga, there are approximately 120 cacti species (Batista *et al.* 2018), with emphasis on the states of Bahia and Minas Gerais. In the Caatinga, Cactaceae is one of the top four species rich plant families, with 99 species and 25 genera recorded and a high degree of endemism (Zappi & Taylor 2020). These plants are widely recognized for their ecological (continuous production of flowers and fleshy fruits, mutualistic interactions of

pollination and seed dispersal by a wide range of animals) and economic (use as fodder, ornamental plants, and in traditional medicine) values (Zappi *et al.* 2011; Gomes *et al.* 2014a, b; Leal *et al.* 2017; Cavalcante *et al.* 2016).

Despite their ecological relevance, many cacti are considered endangered species, with a conservation alert for the cactus family published by Goettsch *et al.* (2015). The authors conducted a global assessment and found that nearly 1/3 of the cacti species are at risk of extinction. In Brazil, Cactaceae is the 6th (out of 10) most endangered family of the national flora (Martinelli *et al.* 2013; Machado *et al.* 2013). The main threats are related to human activities, fragmentation, loss of habitat quality, mining, illegal trade of specimens and seeds, as well as intrinsic (e.g. slow growth and low recruitment rates) and natural factors (e.g. microendemisms, fire) (Zappi *et al.* 2011).

According to the Ministry of Environment Document – Brazil MMA-443/2014, 75 cacti species are listed with different threat categories, including 32 species that occur in the Brazilian Caatinga (Batista *et al.* 2018; Zappi & Taylor 2020). *This scenario might be even more severe since* several cacti are classified as data deficient due to the lack of studies. Additionally, it is worth mentioning that the human population in the Caatinga is large, with approximately 28.6 million people living in the Brazilian Caatinga (IBGE 2010; Silva *et al.* 2017), most of which are dependent on natural resources, thereby causing different impacts on the ecosystem. Therefore, strategies focused on *in situ* and/or *ex situ* conservation approaches in this region are essential.

In the paper "Global diversity and conservation priorities in the Cactaceae", Ortega-Baes & Godínez-Alvarez (2006) point out that according to the IUCN Cactus and Succulent Specialist Group, financial support for cactus conservation actions should ideally focus on: taxonomic studies, evaluating the conservation status of species, *in situ* protection, *ex situ* protection, developing efficient national regulations, controlling national and international trade, and educational programs. In 2011, the Chico Mendes Institute (ICMBio) published the National Action Plan for the Conservation of Cacti, with the aim of promoting effective conservation by reducing the extinction risks of cacti in Brazil (Ribeiro-Silva *et al.* 2011). Successful initiatives for to maintain cacti outside their natural environment using several *ex situ* methods such as: *in vivo* and *in vitro* collections, seed banks and cryopreservation have been developed by researchers from different Brazilian institutions (e.g. universities, botanic gardens, EMBRAPA) (Assis *et al.* 2011; Gonzaga & Reis 2019).

In order to contribute to the conservation of the cacti species, in September 2014 the Guimarães Duque Cactarium was created at the National Institute of Semiarid, located in the Campina Grande municipality, Paraíba state, as an *ex situ* conservation strategy in the Brazilian Semiarid. In this study, we compiled information from the database obtained through the cacti collection and donations over 6 years (2014-2019). Our aims were: (i) to document the cacti samples preserved in

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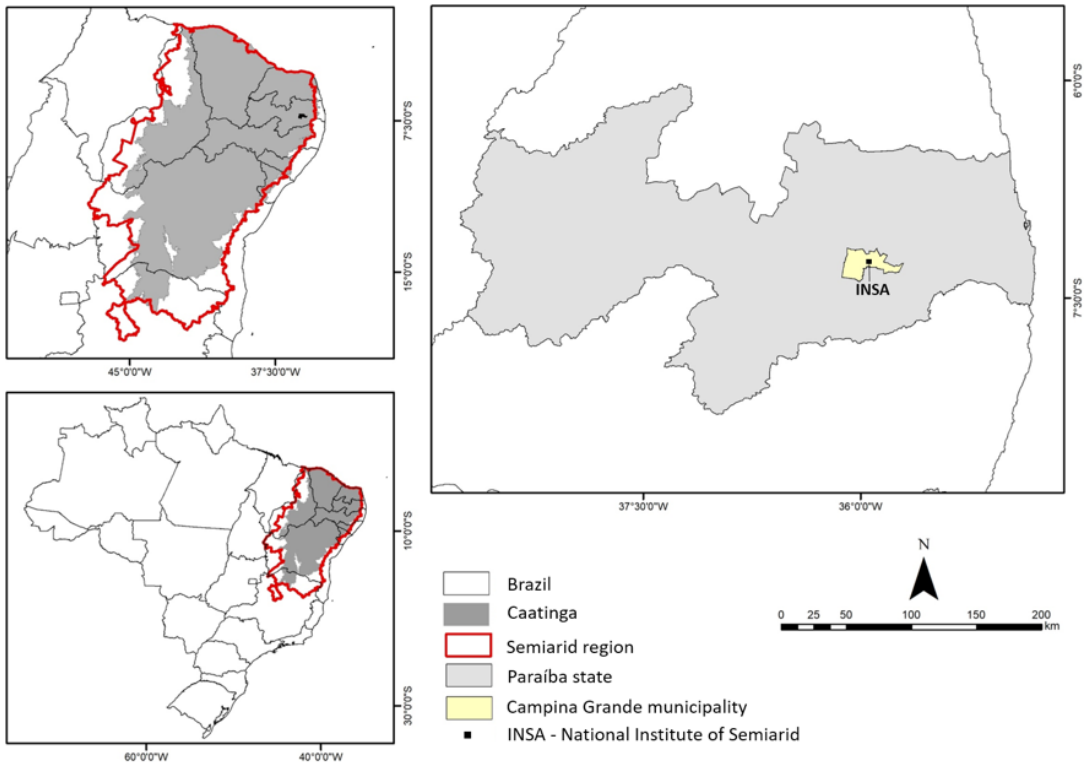
the collection; (ii) identify the most representative genera and species and iii) discuss the main challenges and perspectives of the cactarium supporting *ex situ* conservation actions for Cactaceae.

2 MATERIALS AND METHODS

The Guimarães Duque Cactarium (CAGD) is located at the National Institute of Semiarid (INSA), Campina Grande municipality, Paraíba state, Brazil (7°15'8.95" S and 35°56'45.26" W) (Fig. 1). The institute is a research unit of the Ministry of Science, Technology and Innovations (MCTI) that focuses on conducting studies in the Brazilian semiarid region. The Brazilian Semiarid region is characterized by accentuated seasonality and extreme climatic conditions (e.g. high radiation, low relative humidity and cloudiness). The average annual rainfall is about 800 mm, irregularly distributed throughout the year, with high average annual temperature (27 ºC) (Cavalcante *et al.* 2017).

Figure 1. Location of the Guimarães Duque Cactarium at National Institute of Semiarid, Campina Grande municipality, Paraíba state, Brazil. *Geographic Coordinate System, SIRGAS 2000 Datum.* Source: IBGE/INSA/MMA. Produced by Cícero Fidelis.



The Cactarium is affiliated with the Biodiversity department and was created in September 2014. Its structure occupies an area of 300m² including greenhouses, stands and external gardens. An overview of the cactarium structure and a brief history can be found in Cavalcante *et al.* (2017) and Batista *et al.* (2018). Currently, the cactarium is composed of a permanent exposure structure open

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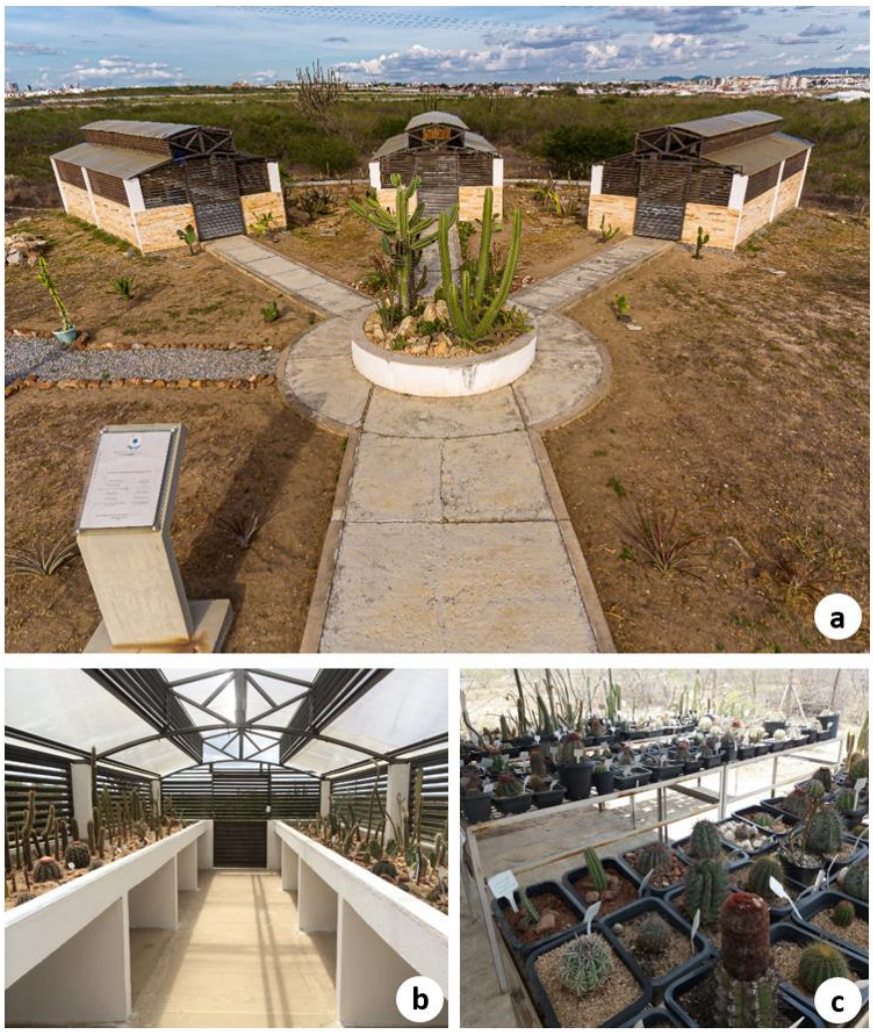
to the public (Fig.2 a,b) and the scientific collection for restricted use (Fig. 2c). The exposure's collection includes species native to the Brazilian Semiarid region and other parts of Brazil, as well as from around the world, and has an important role in scientific dissemination through guided visits. The scientific collection especially preserves native species from the Brazilian Semiarid that are considered of interest for conservation and research.

Figure 2. External (a) and internal (b) view of the permanent exposition structure of the Guimarães Duque Cactarium. c. Partial view of scientific collection. Photos by F. Lavorato and C. Cassimiro.



The inventory of the collection was carried out in March 2020. To enrich the collection, specimens were collected during periodic field expeditions, and were donated or exchanged with partner institutions (e.g. CETENE, UFPB, UNIVASF, IFPB, UFMS). To date, dozens of expeditions have been carried out between 2014-2019 in different states of the Brazilian Semiarid. After the collections, the material was stored in a vase or concrete countertops and cataloged, where it was labelled with an ID number and incorporated into the database and the *in vivo* collection of the Guimarães Duque Cactarium.

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The ID number also called CAGD-ID integrates the database of the cactarium. This database corresponds to a set of specific information about each plant in the collection (e.g. scientific name, popular name, site and date of collection, collector, herbarium voucher, habit, geographic coordinate, conservation status, morphological traits, phenology, etc). The database is periodically updated, providing accurate information about vigorous, diseased and dead plants. When a specimen dies, the individual is removed with the appropriate notes. Such data are meticulously revised ensuring the scientific rigor of the publications.

Botanical identification was carried out based on morphological characterization of the species in the field and laboratory, complementary consultations with specialists, *in loco* visits to the herbariums, as well as by consulting the Cactaceae from digital herbarium catalogues (e.g. *Reflora Virtual Herbarium***; Species link)**. Reproductive parts were fixed in 70% alcohol and an image bank of flowers, pollen, fruits and seeds is being developed for further studies. Whenever possible, fertile specimens were collected for herborization following specific procedures (Zappi 1994). Vouchers were deposited in the Jaime Coelho de Moraes Herbarium (EAN) at the Federal University of Paraíba, Areia municipality.

3 RESULTS

The collection at the Guimarães Duque Cactarium comprises 158 species and 1013 specimens, including Cactaceae and succulent representatives of other botanical families. Currently, a total of 952 cacti specimens belonging to 123 species distributed in 36 genera have been registered (Table 1). Of this total, 104 species are native to Brazil and 19 are exotic species from nine countries, with emphasis on Mexico. The collection also includes succulent plants from eight families, totaling 35 species and 61 specimens. Apocynaceae (N = 2 species; 2 individuals), Asteraceae (N = 1 specie; 2 individuals), Bromeliaceae (N = 8 species; 16 individuals), Crassulaceae (N = 6 species; 10 individuals), Euphorbiaceae (N = 7 species; 11 individuals), Linderniaceae (N = 1 species; 4 individuals), Orchidaceae (N = 2 species; 4 individuals) and Xanthorrhoeaceae (N = 8 species; 12 individuals).

Of the 273 cacti species that occur in Brazil, (N = 104) are represented in the collection, including representatives of the Caatinga, Cerrado, Atlantic Forest, Amazon, Chaco and Pantanal, with emphasis on the endemic and threatened species that occur in the diverse ecosystems of the Brazilian semiarid region, especially the Caatinga. Of the 120 cacti species that occur in the Brazilian Semiarid, (N = 83) are represented in the collection.

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Table 1. List of cacti species preserved in the collection at the Guimarães Duque Cactarium of the National Institute of Semiarid, Paraíba state, Brazil, March 2020. Nomenclature and origin according to Flora do Brasil 2020. (✓) Species that occurs in the Brazilian Semiarid. Conservation status: (LC) Least concern; (NT) Near threatened; (VU) Vulnerable; (EN) Endangered; (CR) Critically endangered.

Species	Origin	Brazilian semiarid	Conservation Status	
			MMA/2014	IUCN Red List
Arrojadoa bahiensis (P.J.Braun & Esteves) N.P.Taylor & Eggli	Native	✓	EN	VU
Arrojadoa penicillata (Gürke) Britton & Rose	Native	✓	-	LC
Arrojadoa rhodantha (Gürke) Britton & Rose	Native	✓	-	LC
***Arrojadoa* sp.**	Native		-	-
Astrophytum ornatum (DC.) Britton & Rose	México		-	VU
Austrocylindropuntia subulata (Muehlenpfordt) Backeb.	Peru		-	LC
Brasilicereus phaeacanthus (Gürke) Backeb.	Native	✓	-	EN
Brasiliopuntia brasiliensis (Willd.) A.Berger	Native	✓	-	LC
Cereus albicaulis (Britton & Rose) Luetzelb.	Native	✓	-	LC
****Cereus fernambucensis*** Lem. subsp. ***fernambucensis***	Native	✓	-	LC
Cereus hexagonus (L.) Mill.	Native		-	LC
Cereus hildmannianus K.Schum.	Native		-	LC
Cereus jamacaru subsp. ***calcirupicola*** (F.Ritter) N.P.Taylor & Zappi	Native	✓	-	LC
****Cereus jamacaru*** DC. subsp. ***jamacaru***	Native	✓	-	LC
Cereus trigonodendron K.Schum. ex Vaupel	Native		-	LC
***Cereus* sp.**	Native		-	-
Cleistocactus baumannii (Lem.) Lem.	Native		-	LC
Coleocephalocereus aureus Ritter	Native	✓	-	LC
Coleocephalocereus decumbens Ritter	Native	✓	-	-
Coleocephalocereus goebelianus (Vaupel) Buining	Native	✓	-	EN
Coleocephalocereus purpureus (Buining & Brederoo) Ritter	Native	✓	EN	CR
Cumulopuntia sphaerica (C.F.Forst.) E.F.Anderson	Chile/ Peru		-	LC
Discocactus bahiensis Britton & Rose	Native	✓	VU	VU
Discocactus ferricola Buining & Brederoo	Native		-	EN
****Discocactus zehntneri*** Britton & Rose subsp. ***boomianus*** (Buining & Brederoo) Taylor & Zappi	Native	✓	-	NT
***Discocactus* sp.**	Native		-	-
Echinocactus grusonii Hildm.	México		-	EN
Echinopsis ancistrophora Speg.	Argentina/ Bolívia		-	VU
Echinopsis calochlora K.Schum.	Native		CR	LC
Echinopsis rhodotricha K.Schum.	Native		-	LC
Epiphyllum phyllanthus (L.) Haw. subsp. ***phyllanthus***	Native		-	LC
Espostoopsis dybowskii (Rol.-Goss.) Buxb.	Native	✓	EN	VU
Facheiroa squamosa (Gürke) P.J.Braun & Esteves	Native	✓	-	LC
Facheiroa ulei (Gürke) Werderm.	Native	✓	EN	LC
Ferocactus herrerae J.G.Ortega	México		-	VU
Frailea cataphracta (Dams) Britton & Rose	Native		-	NT
Frailea gracillima (Lem.) Britton & Rose subsp. ***horstii*** (F.Ritter) P.J.Braun & Esteves	Native		-	VU
Harrisia adscendens (Gürke) Britton & Rose	Native	✓	-	LC

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Hylocereus setaceus (Salm-Dyck) R.Bauer	Native	✓	-	LC
***Hylocereus* sp.**	Native		-	-
Leocereus bahiensis Britton & Rose	Native	✓	-	LC
Lepismium cruciforme (Vell.) Miq.	Native	✓	-	LC
Mammillaria bombycina Quehl & Quehl	México		-	VU
Mammillaria plumosa F.A.C.Weber	México		-	NT
Mammillaria prolifera (Mill.) Haw.	México/ USA		-	LC
Mammillaria spinosissima Lem.	México		-	DD
***** Melocactus* × *albicephalus*** Buining & Brederoo	Native	✓	-	-
Melocactus azureus Buining & Brederoo	Native	✓	EN	EN
****Melocactus bahiensis*** (Britton & Rose) Luetzelb. subsp. ***amethystinus*** (Buining & Brederoo) N.P.Taylor	Native	✓	-	LC
****Melocactus bahiensis*** (Britton & Rose) Luetzelb. subsp. ***bahiensis***	Native	✓	-	LC
Melocactus brederooianus Buining	Native	✓	-	CR
Melocactus concinnus Buining & Brederoo	Native	✓	-	LC
Melocactus conoideus Buining & Brederoo	Native	✓	CR	CR
Melocactus ernestii Vaupel subsp. ***ernestii***	Native	✓	-	LC
Melocactus ferreophilus Buining & Brederoo	Native	✓	EN	CR
Melocactus glaucescens Buining & Brederoo	Native	✓	EN	EN
****** Melocactus* × *horridus*** Wedermann Notizbl.	Native	✓	-	-
Melocactus inconcinnus Buining & Brederoo	Native	✓	-	LC
Melocactus lanssensianus P.J.Braun	Native	✓	EN	EN
****Melocactus oreas*** Miq. subsp. ***cremnophilus*** (Buining & Brederoo) P.J.Braun	Native	✓	-	LC
****Melocactus pachyacanthus*** Buining & Brederoo subsp. ***pachyacanthus***	Native	✓	-	VU
Melocactus paucispinus Heimen & R.J.Paul	Native	✓	VU	LC
Melocactus salvadorensis Werderm.	Native	✓	-	VU
****Melocactus violaceus*** Pfeiff. subsp. ***margaritaceus*** N.P.Taylor	Native	✓	-	VU
****Melocactus violaceus*** Pfeiff. subsp. ***violaceus***	Native	✓	-	VU
Melocactus zehntneri (Britton & Rose) Luetzelb.	Native	✓	-	LC
***Melocactus* sp.**	Native		-	-
Micranthocereus aureispinus F.Ritter	Native	✓	-	-
Micranthocereus flaviflorus Buining & Brederoo	Native	✓	-	NT
Micranthocereus polyanthus (Werderm.) Backeb.	Native	✓	-	EN
Micranthocereus purpureus (Gürke) F.Ritter	Native	✓	-	LC
Micranthocereus streckeri Van Heek & Van Criek.	Native	✓	CR	CR
***Micranthocereus* sp.**	Native		-	-
Nopalea cochenillifera (L.) Salm-Dyck	México		-	DD
Opuntia elata Salm-Dyck	Native		-	LC
Opuntia ficus-indica (L.) Mill.	México		-	DD
Opuntia microdasys (Lehm.) Lehm. ex Pfeiff.	México		-	LC
Opuntia pusilla (Haw.) Nutt.	USA		-	LC

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Parodia magnifica (F.Ritter) F.H.Brandt	Native		-	EN
Parodia scopa (Spreng.) N.P.Taylor	Native		EN	VU
***Parodia* sp.**	Native		-	-
Pereskia aculeata Mill.	Native	✓	-	LC
Pereskia aureiflora Ritter	Native	✓	VU	EN
Pereskia bahiensis Gürke	Native	✓	-	LC
Pereskia bleo (Kunth) DC.	Colombia /Panama		-	LC
Pereskia grandifolia Haw.	Native	✓	-	LC
Pilosocereus aureispinus (Buining & Brederoo) Ritter	Native	✓	-	VU
Pilosocereus azulensis N.P.Taylor & Zappi	Native	✓	CR	CR
****Pilosocereus brasiliensis*** (Britton & Rose) Bakeb subsp. ***ruschianus*** (Buining & Brederoo) Zappi	Native	✓	-	LC
****Pilosocereus catingicola*** (Gürke) Byles & Rowley subsp. ***catingicola***	Native	✓	-	LC
****Pilosocereus catingicola*** (Gürke) Byles & Rowley subsp. ***salvadorensis*** (Werderm.) Zappi	Native	✓	-	LC
Pilosocereus chrysostele (Vaupel) Byles & G.D.Rowley	Native	✓	-	NT
****Pilosocereus floccosus*** Byles & Rowley subsp. ***quadricostatus*** (Ritter) Zappi	Native	✓	EN	LC
Pilosocereus glaucochrous (Werderm.) Byles & G.D.Rowley	Native	✓	VU	LC
Pilosocereus gounellei (F.A.C.Weber) Byles & Rowley subsp. ***gounellei***	Native	✓	-	LC
****Pilosocereus gounellei*** (F.A.C.Weber) Byles & Rowley subsp. ***zehntneri*** (Britton & Rose) Zappi	Native	✓	-	LC
Pilosocereus magnificus (Buining & Brederoo) Ritter	Native	✓	EN	EN
Pilosocereus multicostatus Ritter	Native	✓	EN	EN
****Pilosocereus pachycladus*** F.Ritter subsp. ***pachycladus***	Native	✓	-	LC
****Pilosocereus pachycladus*** subsp. ***pernambucoensis*** (Ritter) Zappi	Native	✓	-	LC
****Pilosocereus pachycladus*** F. Ritter subsp. ***viridis*** N.P.Taylor & Albuquerque-Lima	Native	✓	-	LC
****Pilosocereus pentaedrophorus*** (Cels) Byles & Rowley subsp. ***pentaedrophorus***	Native	✓	-	LC
****Pilosocereus pentaedrophorus*** (Cels) Byles & Rowley subsp. ***robustus*** Zappi	Native	✓	-	LC
Pilosocereus tuberculatus (Werderm.) Byles & G.D.Rowley	Native	✓	-	LC
***Pilosocereus* sp.**	Native		-	-
***Pseudoacanthocereus brasiliensis* (**Britton & Rose) Ritter	Native	✓	-	VU
Rhipsalis baccifera (J.M.Muell.) Stearn subsp. ***baccifera***	Native	✓	-	LC
Rhipsalis cereuscula Haw.	Native	✓	-	LC
Rhipsalis crispata (Haw.) Pfeiff.	Native	✓	-	EN
Rhipsalis floccosa Salm-Dyck ex Pfeiff.	Native	✓	-	LC
Rhipsalis lindbergiana K.Schum.	Native	✓	-	LC
Stenocereus pruinosus (Otto) Buxb.	México		-	LC
Stephanocereus leucostele (Gürke) A.Berger	Native	✓	-	LC
Stephanocereus luetzelburgii (Vaupel) N.P.Taylor & Eggli	Native	✓	-	LC
Tacinga braunii Esteves	Native	✓	VU	VU
Tacinga funalis Britton & Rose	Native	✓	-	LC
Tacinga inamoena (K.Schum.) N.P.Taylor & Stuppy	Native	✓	-	LC
Tacinga lilae (Trujillo & Marisela Ponce) Majure & R.Puente	Venezuela		-	-
Tacinga palmadora (Britton & Rose) N.P.Taylor & Stuppy	Native	✓	-	LC

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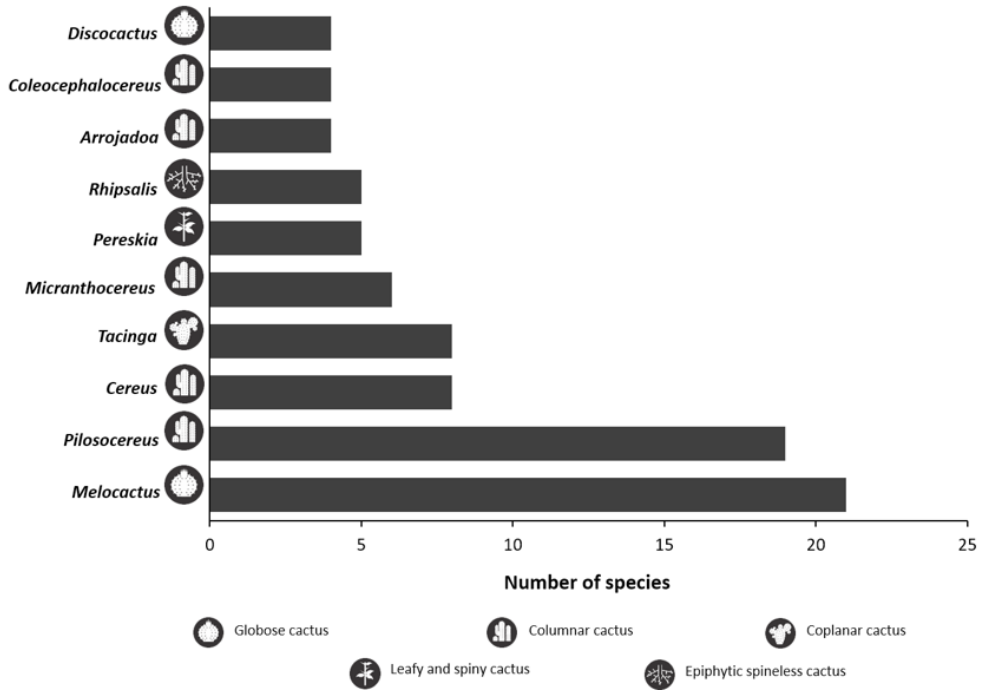
Tacinga subcylindrica M.Machado & N.P.Taylor	Native	✓	-	EN
Tacinga werneri (Eggli) N.P.Taylor & Stuppy	Native	✓	-	LC
******** ***Tacinga* × *quipa*** (F.A.C.Weber) N.P.Taylor & Stuppy	Native	✓	-	-
Thelocactus rinconensis (Poselg.) Britton & Rose	México		-	LC
Turbinicarpus pseudomacrochele (Backeb.) Buxb. & Backeb.	México		-	EN

* Information regarding the status of the species in the IUCN Red List; ** *Melocactus* × *albicephalus* is a natural hybrid between *M. glaucescens* and *M. ernestii*; *** *Melocactus* × *horridus* is a natural hybrid between *M. ernestii* and *M. zehntneri;* **** *Tacinga* × *quipa* is a natural hybrid between *T. palmadora* and *T. inamoena.*

The most representative genera in the collection are *Melocactus* Link & Otto and *Pilosocereus* Byles & G. D. Rowley, with 21 and 19 species respectively, followed by *Cereus* Mill. and *Tacinga* Britton & Rose, both with 8 species (Fig. 3). The most abundant species in the collection are *Tacinga inamoena* (K.Schum) N. P. Taylor & Stuppy, *Melocactus zehntneri* (Britton & Rose) Lutzelb., *Discocactus zehntneri* subsp. *boomianus* (Buining & Brederoo) N.P.Taylor & Zappi and *Discocactus bahiensis* Britton & Rose. In the cactarium, there are representatives of three monotypic genera (*Brasiliopuntia brasiliensis* (Willd.) A. Berger, *Espostoopsis dybowskii* (Gosselin.) Buxb. and *Leocereus bahiensis* (Britton & Rose)) and three natural hybrids (*Melocactus* × *albicephalus* Buining & Brederoo, *Melocactus* × *horridus* Werderm. and *Tacinga* × *quipa* (F.A.C.Weber) N. P. Taylor & Stuppy).

Figure 3. *Top 10 genera* with highest cacti species diversity in the collection at the Guimarães Duque Cactarium of the National Institute of Semiarid, Paraíba state, Brazil.



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Considering only the native Brazilian cacti maintained in the collection, 21 species are classified with different threat categories according to the MMA/ 2014 list and 35 species according to the IUCN Red List (Table 1). Some threatened cacti species conserved in the cactarium are illustrated in Figure 4. We highlight that there are representatives with all threat categories, with four and six Critically Endangered species according to MMA / 2014 and IUCN Red List, respectively (Fig. 5a). The most representative genera of the collection also presented a greater number of species in different threat categories, which were *Melocactus* (Fig. 5b) and *Pilosocereus* (Fig. 5c).

Figure 4. Examples of cacti endangered species preserved in the collection at the Guimarães Duque Cactarium of the National Institute of Semiarid, Paraíba state, Brazil. a. *Arrojadoa bahiensis* (Vulnerable); b. *Pilosocereus azulensis* (Critically endangered); c. *Micranthocereus polyanthus* subsp. *alvinii* (Endangered); d. *Discocactus bahiensis* (Vulnerable); e. *Tacinga subcylindrica* (Endangered); f. *Pereskia aureiflora* (Endangered); g. *Melocactus azureus* (Endangered); h. *M. lanssensianus* (Endangered); *M. conoideus* (Critically endangered). Photos by A. Neves, F. Lavorato, J. Freitas and V. Gomes.

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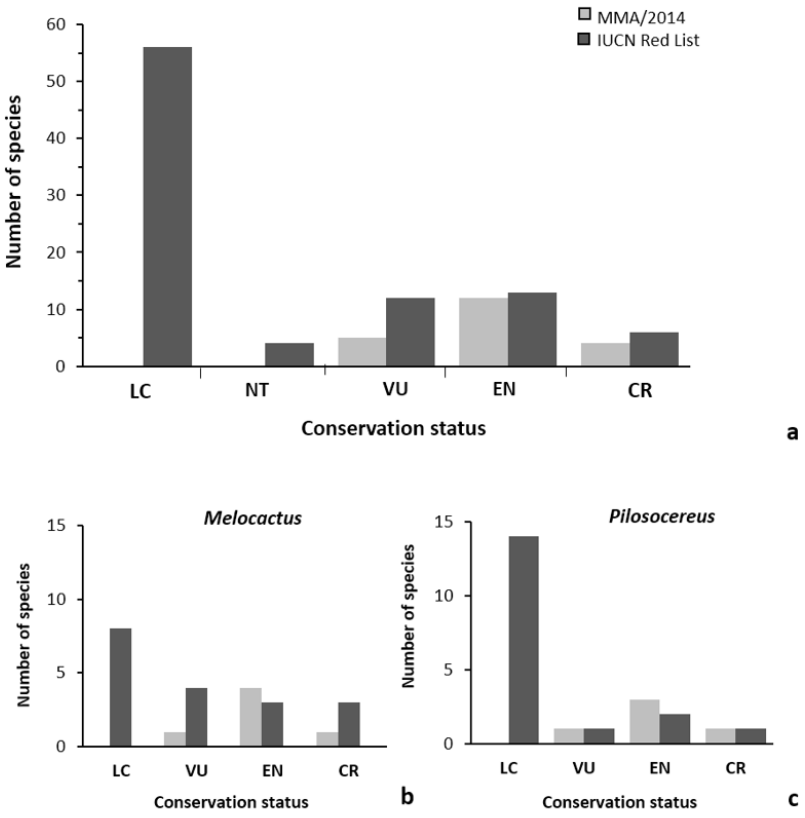
Figure 5. a. Number of species classified with different threat categories maintained in the collection at the Guimarães Duque of the National Institute of Semiarid, Paraíba state, Brazil. Number of threatened species in the most representative genera of the collection: b. *Melocactus* and c. *Pilosocereus*. Classification according to MMA/ 2014 list and IUCN Red List considering only native species of Brazil. (LC) Least concern; (NT) Near threatened; (VU) Vulnerable; (EN) Endangered; (CR) Critically endangered.



4 DISCUSSION

The collection at the Guimarães Duque Cactarium comprises 35% of the Brazilian cactus diversity (Zappi & Taylor 2020), demonstrating the wide diversity of habits and life-forms of the family (columnar, globose, coplanar, epiphytes, shrubby with leaves). Of the Brazilian species in the collection, the largest volumes come from the Brazilian Semiarid region, with 70% of the Brazilian Semiarid cacti species represented into the collection. This high percentage consolidates the Guimarães Duque Cactarium as a representative regional collection for the Cactaceae family.

Like the Guimarães Duque Cactarium, other Brazilian institutions are also involved in the *ex situ* conservation of Cactaceae. In the Northeast, we highlight the Cactarium at the Botanical Garden of Recife, Pernambuco (Pimentel & Maciel 2018), and the cacti collection of Embrapa Tropical Agroindustry for Cactaceae in Fortaleza, Ceará (Coelho *et al.* 2015), both of which have high species richness in their respective states. Additionally, there are *in vivo* and *in vitro* collections at the Biology Institute of the Federal University of Bahia, the *Banco Ativo de Germoplasma de Cactáceas* (BACG) of the State University of Feira de Santana (Assis *et al.* 2011), the seed and *in vivo* collections at the

Federal University of Vale do São Francisco, with 24 and 57 cacti species native to the Caatinga, respectively (HVASF 2013). Along with their recognized regional representativeness, these collections guarantee conservation and use germplasm for different purposes, especially basic research in different areas. (Assis *et al.* 2011).

As evidenced by Mounce (2017), botanical gardens conserve plant diversity *ex situ* and can prevent extinction through integrated conservation actions. For example, in Rio de Janeiro, the collection at the Cactarium of the Rio de Janeiro Botanical Garden houses 236 species, including native and exotic cacti and other succulents. Unlike the Guimarães Duque collection, the most abundant cacti species in the Rio de Janeiro Cactarium are from southeastern Brazil, with emphasis on the Espinhaço and Mantiqueira ranges (Gonzaga & Reis 2019). Other examples include cactus collections from the Botanical Garden of Brasilia (Carvalho-Silva *et al.* 2009), the Zoobotanic Foundation of Belo Horizonte in Minas Gerais state (Fernandes *et al.* 2001) and the Horst Cactarium located in the Rio Grande do Sul state, which is considered the largest Cactarium in Latin America (Zanchi *et al.* 2017). Despite being a commercial enterprise, this cactarium promotes preservation actions (Pontes *et al.* 2017).

Another important aspect of the collection is the number of species presenting threat categories in the Guimarães Duque Cactarium, with 21 species labelled according to MMA/ 2014 list and 35 species according to IUCN Red List. We concentrated our collection efforts on prioritizing endemic and threatened species of the Semiarid Brazilian. This effort focused on threatened species follows the recommendations of the strategic plan proposed by Silveira *et al.* (2018), so Brazil can achieve the Target 8 of the Global Strategy for Plant Conservation; a challenge for 2020-2030.

Challenges and perspectives of the Guimarães Duque Cactarium

The collection of the Cactarium is a resource for current and future studies about cacti biodiversity. The collection supports research carried out by INSA's Biodiversity group in the areas of Agroecology, Molecular Biology, Biochemistry, Cytogenetics, *in vitro* Cultivation, Ecology, Taxonomy and Systematics (Castro *et al.* 2016; Batista *et al.* 2018; Amaral *et al.* 2020; Castro *et al.* 2020; Marhold *et al.* 2020a, b). In addition to the *in vivo* collection, the institute maintains an *in vitro* cactus collection, with about 3,000 specimens, representing 27 species (Batista *et al.* 2018). The collections carried out by the Biodiversity group expanded the occurrence area of five cacti species, adding four and one new occurrence records to Paraíba and Minas Gerais states, respectively (Batista *et al.* 2018). These geographic records could provide input for biodiversity and biogeographical studies. In parallel, we also developed Environmental Education and Popularization of Science

activities, through scientific dissemination during guided visits to the Cactarium, receiving students from elementary education to post-graduation.

Briefly, the main challenges include maintaining the collection, identifying species gaps and selecting priority collection areas. In order to maintain specimens, the collection requires a controlled environment and trained human resources who constantly and accurately care for each individual plant, by watering, pruning, reviewing substrate and controlling diseases. According to Gonzaga & Reis (2019), the protected cultivation of cacti species in greenhouses is recommended to minimized damage, as well as rigorous control of fungi and bacteria through the application of fertilizers and pesticides. Regarding the collection gaps, we highlight the need for more sampling to adequately fill in the cacti species missing from the collection, especially those occurring in the Sergipe, Piaui and Maranhão states. Examples of such gaps revealed in this inventory are *Facheiroa cephaliomelana* Buining & Brederoo, *Melocactus sergipensis* N.P.Taylor & M.V.Meiado and *Pilosocereus piauhyensis* (Gürke) Byles & G.D.Rowley.

Through multidisciplinary and complementary studies, the collection helps address questions about discovery of new species, evaluate aspects of reproductive ecology, hybridization, as well as improve cultivation techniques for certain groups with restricted habitats and specific germination requirements. Therefore, we aim to expand and formalize new partnerships, increase the richness and abundance of the collection in *vivo* and *in vitro,* and participate and establish ecological restoration programs using seedlings to recover populations of threatened species in their natural environment. Thus, we expect to expand and advance the scientific knowledge of cacti species by integrating different strategies that support the conservation of these plants that are a symbol of the Brazilian Semiarid region.

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