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Beekeeping Potential of the Caatinga Vegetation: Apicultural Potential of the Caatinga Flora in the Dry Season.

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A B S T R A C T

The Caatinga, a dry forest vegetation of northeastern Brazil, has a diverse flora high species number and β diversity, but remains under-sampled. Clime and vegetation make the region a great beekeeping producer, and floristics surveys are essential to the preservation and multiplication of focal species for the activity. The state of Piauí has been prominent as honey producer, especially in the Caatinga areas. However, due to the dry season, that could decrease the amount of food disponible, it´s necessary to evaluate the richness of species found during this season and their potential as forage. We surveyed plant species occurring in the Caatinga of municipality of Fartura do Piauí, describing their floral characteristics, flowering phenology, and resources for Apis mellifera L. bees, during both the dry and rainy seasons. We identified 58 species, most with floral attributes associated with melittophily syndrome and DPI offering nectar and pollen as resources. Among these, 11 flowered in the dry period, providing a valuable source of bee pasture.

Keywords: Beekeeping, Caatinga, Dry season, Flora.

Potencial Apícola da Vegetação da Caatinga: Apicultura da Flora da Caatinga no Período Seco.

R E S U M O

A Caatinga, vegetação do Nordeste do Brasil, possui uma flora diversa, alta β diversidade, mas é subamostrada. O clima e a vegetação fazem da região um grande produtor apícola, sendo os trabalhos florísticos imprescindíveis para preservação e multiplicação das espécies focais para essa atividade. O estado do Piauí é destaque na produção de mel, especialmente nessas áreas. No entanto, devido ao período seco, que pode diminuir a quantidade de alimento disponível para as abelhas, é necessário avaliar a riqueza de espécies encontradas durante esta estação e seu potencial como forragem. Esse estudo levantou as espécies ocorrentes na Caatinga, descrevendo seus caracteres florais e avaliando a disponibilidade das flores e seus recursos para as abelhas *Apis mellifera* L., durante as estações seca e chuvosa, no município de Fartura do Piauí. Identificamos 58 espécies, grande parte com atributos florais relacionados a síndrome de melitofilia e DPI, oferecendo como recurso néctar e pólen e destas, 11 florescem no período seco, fornecendo pasto apícola apropriado aos enxames.

Palavras-chave: Apicultura, Caatinga, Escassez hídrica, Flora.

Introduction

The Caatinga is the major dry tropical forest of South America (Pennington et al., 2000). It occupies about 900 thousand square kilometers of northeastern Brazil, comprising approximately 54% of the region's total area (Andrade et al., 2005). The climate is harsh, with strong seasonality, high temperatures (from 25° to 30°C), and extremely low rainfall, ranging from 600 to 1000 mm annually (Da Silva et al., 2017; Sampaio, 2003). Because of these environmental conditions, the plant species exhibit various types of adaptation to water stress, such as deciduous leaves, annual herbs, succulence, needles, thorns, small trees, and shrubs (Giuliette et al., 2004; Pennington et al., 2006; Rodal et al., 2013; Rodal and Sampaio, 2002). Nevertheless, its flora is very rich and heterogeneous, recording high beta diversity and

endemism, with approximately 23% of species and 31% of genera endemic to the vegetation (Da Silva et al., 2017; Pennington et al., 2006; Pennington et al., 2009). Regardless, these numbers may still be underestimated, because large areas of this ecosystem remain uncollected or under-sampled (De Queiroz et al., 2017; Moro et al., 2014).

The flora of the Caatinga also stands out due to its beekeeping potential, driven by plant species richness and warm temperatures, which provide a good environment for African honeybees (Freitas, 1991; Lima, 1995). In fact, the Northeast of Brazil, where this vegetation dominates, is also the second largest honey producer in the country and has gained prominence in the organic type, with low contamination from pesticides and antibiotics, relying on the native vegetation (Vidal, 2021 and 2022). Due to its low implementation and maintenance costs, in addition to quick financial returns, the rational breeding of *Apis mellifera* L. bees is one of the zootechnical activities that has grown the most in recent years in this region (Vidal, 2013). Between 1999 and 2009, northeastern honey production increased from 2,795 tons to 14,963 tons, a growth of 435% (Vidal, 2013). This beekeeping activity presents itself as a viable alternative for generating income and employment in rural areas, while also contributing to the preservation of native flora (Andrade et al., 2014).

Despite the success of establishing African honeybees and their adaptation to the semi-arid climatic conditions of the Northeast region, apiculture, like other agribusinesses, is vulnerable to climate variations such as extreme low rainfall or long dry seasons (Ribeiro et al., 2021; Silva, 2024; Vidal, 2017). The strong dry season that occurred in the area in 2012 drastically decreased the availability of food for the bees, which can result in a decrease in bee populations and honey production (De Sousa et al., 2021; Vidal, 2020). Honey production in the Northeast region is still recovering from this long drought that has influenced production since mid-2012. Only the State of Piauí has shown a high recovery in productivity in 2021 and is responsible for 73% of the region's exported honey, mostly due to a good rainy season in 2021 (Vidal, 2023). In conclusion, this suggests that beekeeping production is severely affected by drought and irregular rainfall. Potentially, climate change with its increase and more frequent extreme weather events, can further impact beekeeping around the world and in the region, with changes in the precipitation and temperature patterns being the main impact factor (Marengo et al., 2020; Zapata-Hernández et al., 2024).

During the drop in available floral resources for bees, beekeepers can use artificial food to maintain the population (Castagnino et al., 2006; Pinho et al., 2018; Rana and Singh, 2024). However, this approach can increase production costs and the final price of honey (Saffari et al., 2010). We propose that a floristic survey focusing on the dry season, can identify plant species that bees seek nectar and pollen. This knowledge would allow for the future increase and protection of these plants in local bee pastures or the selection of appropriate areas for installing hives (Wolff et al., 2009). By identifying and evaluating plant species that offer food during the dry period, it is possible to develop strategies that avoid low production and hive abandonment during the season (Silva et al., 2015). Furthermore, this approach can enable the multiplication and preservation of these valuable plant species (Santos Junior and Santos, 2002).

The floral traits of the plant species can also be used to evaluate these aspects. Plant reproductive characters, including size, color, flower type, and floral resources, can provide information about the possible pollinators of these species. These suites of traits, known as pollination syndromes, represent congruent traits present in different plant species associated with a particular group of pollinators (Endress, 1994; Faegri and Pijl, 1979; Hassan et al., 2024; Proctor et al., 1996). These attributes can be used to characterize and provide information related to the functioning of communities (Fontaine et al., 2006; Girão et al., 2007; Machado and Lopes 2004; Martins and Batalha, 2006; Oliveira and Gibbs 2000; Rocha-Santos et al., 2020; Sobrevilla and Arroyo, 1982; Vamosi et al., 2006; Zapata and Arroyo 1978). In our case, these floral traits can help us identify species with melittophily syndrome (pollination by bees) or with generalist characteristics, offering resources more easily accessible to Africanized bees (Pigozzo and Vianna, 2010).

The Piauí State, in northeastern Brazil, has vast areas of Caatinga vegetation that are under-sampled or unsampled at all, including the Serra da Capivara National Park region, which is only represented by two works (Lemos, 2004; Lemos and Rodal, 2002). The Serra da Capivara territory is a region with floristic diversity and little-studied ecological relationships. It is also an agricultural area of beekeeping importance (Abreu et al., 2024; CEPRO, 2011) with the microregion classified as the second largest honey producer in the State of Piauí (Carvalho et al., 2019). The municipality of Fartura do Piauí exemplifies this growth. In 2019, it produced 58,360 kg of honey, and in 2020, its production almost doubled, reaching 101,180 kg (IBGE, 2023). However, despite these impressive

numbers, beekeeping in the region still suffers from limitations. These limitations include a low level of professionalization, difficulty in accessing technology and technical assistance, and general infrastructure issues, all which harm production value (Vidal, 2023). Adding to these challenges is the lack of knowledge about bee flora. A more complete understanding of this floral composition is necessary for the further development of beekeeping in the state (Aleixo, Araújo, Agra, Maracajá and Sousa, 2014).

Based on what has been presented, studies on floristic composition, floral characteristics, floral resources, and pollination systems are imperative for both conservation purposes and honey production. This is due to the importance of native vegetation composition in sustaining productive bee colonies (De Borges et al., 2020; Morais et al., 2020; Kremmer et al., 2007; Potts et al., 2010). Therefore, this project aims to survey angiosperm species and their beekeeping potential in the Caatinga area. The species were evaluated through their morphological characteristics, pollination syndromes, and floral resources available to *Apis mellifera* L. bees, with an emphasis on the dry season, in the municipality of Fartura do Piauí, microregion of São Raimundo Nonato, Serra da Capivara Territory, Piauí, Brazil. Our hypotheses are of that (a) the area has a high number of angiosperm plant species, as expected for Caatinga vegetation, (b) richness floral attributes and pollination syndromes and (c) and most of the species' flowering in the wet season, but in dry season the melittophilous and generalists' ones offer nectar and nectar-pollen enabling honeybees' access to floral resources.

Material and Methods

Study Area -This work was carried out in an area of Caatinga in the municipality of Fartura do Piauí – PI (09°00'51" S and 42°41'11" W), microregion of São Raimundo Nonato, Serra da Capivara territory in the south of Piauí. The region has a hot semi-arid tropical climate, with a rainy season lasting seven to eight months, with arboreal and shrubby caatinga vegetation and patches of cerrado countryside (CEPRO, 2000). The research was carried out in areas close to apiaries, in the rural area of the municipality.

Sampling and botanical identification - To evaluate the vegetation regarding the floral resources available and the beekeeping potential of the flora, we established 15 plots of 20m x 20m in caatinga areas throughout the dry and rainy seasons. During the survey for each plots, we sampled all species in the reproductive phase (flower or fruit), following the common field methodology (Mori, 1989; Moro and Martins, 2011), also recording data on life form, phenological phase (Bencke and Morellato, 2002), and floral traits (size, color, and type) involved with the pollinator's attractiveness and floral resources availability to the bees (Endress, 1994; Faegri and Pijl, 1979). Vegetative and reproductive samples of the species were herborized for recording and identification with the aid of dichotomous keys and comparative morphology, using specialized bibliography and through exsiccate analysis. The species were classified according to APG IV (2016) and deposited in the Graziela Barroso Herbarium of the Universidade Federal do Piauí (TEPB-UFPI). With the list of identified species, a database was created where data on reproductive attributes and pollination syndromes were compiled through 1) data collected in the field and 2) information available in specialized literature. The classes of reproductive attributes and pollination syndromes used to characterize the species in this study are described in the following topic.

Floral traits and resources - Five flower size classes were adopted (*sensu* Machado and Lopes, 2004): (1) inconspicuous (≤ 4mm), (2) small (≥ 5 < 10mm), (3) medium (≥ 10 < 20 mm), (4) large (≥ 20 < 30 mm) and (5) very large (≥ 30 mm). Thirteen color classes were considered: (1) yellow, (2) orange, (3) blue, (4) white, (5) cream, (6) greenish (including flowers with green tones), (7) rusty, (8) brown, (9) red, (10) burgundy, (11) green (flowers completely bright green), (12) lilac/violet, (13) pink (in light and dark tones). Ten floral types (sensu Faegri and Pijl, 1979) were considered: (1) achlamyd, (2) bell, (3) chamber, (4) brush, (5) spike (inflorescence with sessile flowers along a rachis, including the spadix type), (6) standard or gullet, (7) inconspicuous (for flowers ≤ 4 mm), (8) plate/disc, (9) infundibuliform and (10) tube (we include and hypocrateriform within this type). For floral resources, six classes were considered: (1) pollen; (2) nectar, (3) pollen and nectar (both resources offered and with the same relative importance. *Sensu* Gottsberger and Silberbauer-Gottsberger, 2006), (4) oil, (5) resin and (6) perfume. Pollination syndromes were classified according to Faegri and Pijl (1979) and Proctor et al. (1996), with eleven types being considered: 1) anemophily (wind), 2) cantharophily (beetles), 3) various small insects (DPI), 4) sphingophily/phalaenophily (moths), 5) melittophily (bees), 6) myophily (flies), 7) ornithophily (birds), 8) psychophily (butterflies), 9) chiropterophily (bats) and 10) wasps.

Reproductive phenology and floral resources - During the period of march/2021 to

february/2022, through the dry and rainy season, we collected the species in the flowering phase, recording their traits and verifying the type of resource available to the africanized bees *(Apis mellifera*), each month. We use this information to contrast with the climatic data of these years, such as average temperature and precipitation. These climate data of Fartura do Piauí station was obtainable in the INMET and Agritempo database.

Data Analysis – A database will be produced with the frequency of families, genera, species, reproductive characteristics, floral resources in a Microsoft Excel Spreadsheets. In the same program, graphs will be created comparing percentage data on phenology flowering, types of floral resources and life forms available for each the average monthly temperature and precipitation.

Results and Discussion

Floristic composition - We identified 65 species from 55 genera and 26 families, exhibiting life forms of herbs (25%), shrubs (28%), trees (37%), climbers (5%), and lianas (6%) (Table 1 and Figure 1). The Fabaceae is the dominant family in species richness (14), followed by Euphorbiaceae (8), Malvaceae (7), Bignoniaceae (4), Convolvulaceae (3), Rubiaceae (3), Acanthaceae (2), Anacardiaceae (2), Boraginaceae (2), Lythraceae (2), Malpighiaceae (2), and Verbenaceae (2). Fifteen families were represented by one recorded species each, such as Amaranthaceae, Annonaceae, Apocynaceae, Asteraceae, Chrysobalanaceae, Erythroxylaceae, Lamiaceae, Lythraceae, Myrtaceae, Plantaginaceae, Polygalaceae, Rhamnaceae, Sapindaceae, Turneraceae, and Ximeniaceae.

Our number of species is representative of the Caatinga flora, as expressed by other works about apicultural flora like Santos et al. (2021) in the county of Alagoinhas (BA), who recorded the Fabaceae family as the most representative with 11 species, followed by Rubiaceae. Also in Bahia State, Fabaceae was the most representative family, followed by Euphorbiaceae, Asteraceae and Malvaceae (Dias et al., 2024). Other families also representative in this study, such as Euphorbiaceae and Malvaceae, were appointed as well in other works for the Caatinga vegetation (e.g., Amaral et al., 2012; Câmara, Ribeiro, Girão, and Loiola, 2021; Lavor and Ramos, 2016; Morais et al., 2020). Lopes et al. (2016) recorded 37 species of the Fabaceae family while surveying a beekeeping flora in Cerrado vegetation in the municipality of Floriano (PI), finding 37 species of Fabaceae, followed by Malvaceae, and 17 families recording one species.

In surveys on vegetation in the state of Piauí, Farias et al. (2008) and Farias and Castro (2004) in the municipality of Campo Maior, an ecotonal transition area, found the Fabaceae family with the largest number of species. Meanwhile, Lemos (2004) in the municipality of São Raimundo Nonato (PI), in a study on the floristic composition of the Serra National Park da Capivara, recorded Fabaceae, Mimosaceae, Bignoniaceae, and Euphorbiaceae as the most representative families. For the state of Piauí, the family Fabaceae is also the most representative in number of tree species if beekeeping interest (Moura et al., 2024).

Fabaceae is among the families with the largest number of species in the Brazilian flora, and stands out in the cerrado vegetation with 1304 species and in the caatinga with 649 species (Flora do Brasil, 2024), presenting itself as the most important for feeding *Apis mellifera* (Ramalho et al., 1990) and is constantly cited in works that seek to identify sources of bee pollen (Alves and Santos, 2014; Dórea et al., 2010). The family also has the largest number of interactions with pollinating species, more than 50% of the species, considering all vegetation formations in Brazil (Valadão-Mendes et al., 2024)

The floristic composition found in this work brought five of the most representative families of the Caatinga dry forest: Apocynaceae, Convolvulaceae, Euphorbiaceae, Fabaceae, Malvaceae (De Queiroz et al., 2017). We, however, noted that some of the most representative families of the ecosystem such as Cactaceae and Bromeliaceae are not recorded and others that are rare in the Caatinga, like Annonaceae and Chrysobalanaceae, were. The first, a family more common in Cerrado vegetation (Ratter et al., 2006), with the species recorded also occurring in rupestrian fields and Caatinga, and the second occurring in cerrado and humid forest (Flora do Brasil, 2025).

This lack of species of Cactaceae and Bromeliaceae can be explained by anthropic changes, since our plots are in areas of Caatinga undergoing regeneration or succession, according to residents, used for agricultural cultivation or pasture, which has been dormant for between 50 and 100 years. We know that areas of the Caatinga that have less richness, less diversity, or dominance of few species are areas that have suffered some type of interference or have been degraded (Pereira et al., 2003). Other families registered that are rare in caatinga vegetation may reflect the area being within a transition region, as the municipality is close to the Serra das Confusões National Park, composed of areas of vegetation between the Caatinga and Cerrado on plateaus and Carrasco (a

type of dry forest) vegetation present in valleys and depressions (Rocha et al., 2005) and, thus, influenced by floristic components from other domains.

Some of the least representative families recorded in this study are herbaceous species, such as those from the Amaranthaceae, Asteraceae, Lamiaceae, Lythraceae, Plantaginaceae, Polygalaceae, and Turneraceae families. This was the life form that was more representative in our work. The herbaceous habit is a life form that is generally little considered in floristic and phytosociological surveys (Munhoz and Araújo, 2011) and, therefore, perhaps underrepresented in general lists for Cerrado or Caatinga. Despite this, plants with herbaceous/shrub habits represent the majority of species in the Caatinga bee flora, even though they are greatly affected by climate and precipitation (Lorenzon et al., 2003; Moraes et al., 2020; Rodarte et al., 2008; Santos and Ribeiro, 2009; Vasconcelos et al., 2021), with a significant reduction in the number of flowers during droughts and blooming more intensely during the rainy season, with the months of March and April being those with the most significant flowering (Moraes et al., 2020).

Floral Traits and pollination syndromes - The species found in Caatinga, in the municipality of Fartura do Piauí (PI), predominantly had small (39%) and very large (23%) flowers (Figure 2a), with a predominance of white (38%) and yellow (23%) (Figure 2b). Regarding the types of flowers, there were greater representations of the tube type (32%), disc (31%), brush, and flag (11%) (Figure 2c). Flower size is generally associated with the size of the respective pollinator or pollination efficiency (Delgado et al., 2023; Naghiloo et al., 2021; Opler, 1980), however, the pollination system should not be inferred based solely on flower size. Examples of species with small flowers that are attractive due to their organization in inflorescences, are found in many legumes, such as *Anadenanthera colubrina*, *Mimosa tenuiflora*. These are in fact classified into floral types relative to the pollination unit, in this case, the inflorescence (Machado and Lopes, 2004).

Figure 1 Surveyed species in Caatinga vegetation next to the beehives, in the region of Fartura of Piauí, Brasil. (A) *Varronia curassavica* Jacq. (Cordiaceae), (B) *Turnera scabra* Millsp. (C) (Turneraceae), *Arrabidea* sp. (Bignoniaceae), (D) *Poeppigia densiflora* Tul. (Fabaceae), (E) *Dolichandra unguis-cati* (L.) L.G.Lohmann (Bignoniaceae), (F) *Erythroxylum pungens* O.E.Schulz (Erythroxylaceae), (G) *Spondias tuberosa* L. (Anacardiaceae), (H) *Amburana cearensis* (Allemão) A.C.Sm (Fabaceae). (Source: research archive).

Of the floral resources offered, nectar was the most common (44%), followed by nectar and pollen (42%), pollen (11%), and oil (3%) (Figure 2d). Resources offered such as pollen and oil are more related to specialized types of pollination and were less frequent in this study. For example, the species of Malpighiaceae, pollinated by solitary oil-collecting bees, Centridini and Tapinotaspidini, represent a more specialized type of melitophilia (Carneiro and Machado, 2023; Rasmussen and Olesen, 2000; Torretta et al., 2022), and Annonaceae, with their chamber-like flowers that offer pollen to their pollinators, which consist of small beetles (Saunders, 2012; Saravy et al., 2023).

Table 1. Plant species their life form recorded in Caatinga vegetation in the municipality of Fartura of Piauí, Brasil.

Family/Species	Common name	Life form
ACANTHACEAE		
Ruellia geminiflora Kunth		herb
Ruellia sp.		shrub
AMARANTACEAE		
Alternanthera brasiliana (L.) Kuntze		herb
ANACARDIACEAE		
Astronium urundeuva (Allemão) Engl.	aroeira	tree
Spondias tuberosa L.	umbuzeiro	tree
ANNONACEAE		
*Annona leptopetala (*R.E.Fr.) H.Rainer	ata brava	shrub
APOCYNACEAE		
Aspidosperma pyrifolium Mart. & Zucc.	pereira de cachorro	tree
ASTERACEAE		
Centraterum panctatum Cass.	cabeça-roxa	herb
BIGNONIACEAE		
Arrabidaea sp.		liana
Cuspidaria lateriflora (Mart.) DC		shrub
Dolichandra unguis-cati (L.) L. G. Lohmann	cipó	liana
Handroanthus Mattos	pau de casca/ipê amarelo	tree
CHRYSOBALANACEAE		
Leptobalanus octandrus (Hoffmanns. ex Roem. & Schult.) Sothers & Prance	folha miúda	tree
CONVOLVULACEAE		
Evovulus sp.	azulzinha	herb
Ipomoea carnea Jac.	jitirana-roxa	climber
Distimake aegyptius (L.) A.R. Simões & Staples	jitirana branca	climber
CORDIACEAE		

Cordia trichotoma (Vel.) Arráb. ex Steud.	frei-jorge	shrub
Varronia curassavica Jacq.	maria preta	shrub
ERYTHROXYLACEAE		
Erythroxylum pungens O.E.Schulz	rompe gibão	tree
EUPHORBIACEAE		
Cnidoscolus quercifolius Pohl.	favela	tree
Cnidoscolus urniger (Pax) Pax	cansanção de boi	shrub
Croton jacobinensis Baill.	vira-folha	shrub
Croton sp1. (45)	quebra-facão	shrub
Croton sp2. (72).	marmeleiro	shrub
Croton campestris A. St.-Hil.	coça-coça	shrub
Croton sp3. (30).	velame	shrub
Jatropha mollissima (Pohl.) Baill.	peão vermelho	shrub
FABACEAE		
Anadenanthera colubrina (Vell.) Brenanvar. Cebill (Griseb.) Altshul.	angico	tree
Amburana cearenses (Allemão) AC Sm.	imburana de cheiro	tree
Bauhinia cheilantha (Bong.) Steud.	miroró/pata de vaca	shrub
Calliandra spinosa Ducke.	triadinho	tree
Dalbergia frutescens (Vell.) Britton	violeta	tree
Lachesiodendron viridiflorum (Kunth) PG Ribeiro, LP Queiroz & Luckow	espinheiro	tree
Luetzelburgia auriculata (Allemão Ducke)	sucupira	tree
Mimosa ophthalmocentra Mart. Ex Benth.	jurema vermelha	tree
Mimosa tenuiflora (Willd.) Poir.	jurema preta	tree
Piptadenia stipulacea (Benth.) Ducke*	jurema branca	tree
Pityrocarpa moniliformis (Benth.) Luckow & R. W. Jobson	angico de bezerro	tree
Poeppigia densiflora Tul.	caracu	tree
Sesbania sp.		liana
Stylosanthes capitata Vogel		herb
LAMIACEAE		
Ballota sp.	bamburral	herb
LYTHRACEAE		
Cuphea campestres Mart. ex Koehne		herb
Cuphea impatientifolia A. St.-Hil.		herb

MALPIGHIACEAE		
Ptilochaeta bahiensis Tucz.	quebradeira	tree
Thryallis sp.		liana
MALVACEAE		
Allobriquetia spicata (Kunth) Bovini		shrub
Helicteres velutina K. Schum.**		shrub
Herissantia tiubae (K.Schum.) Brizick		shrub
Pavonia cancelata (L.) Cav.		herb
Sida sp.	malva-rasteira	shrub
Sida cordifolia L.	malva-babenta	shrub
Waltheria sp.		shrub
MYRTACEAE		
Eugenia dictyophleba O. Berg	azedinha	tree
PLANTAGINACEAE		
Angelonia pubescens Benth.		herb
POLYGALACEAE		
Asemeia violacea (Aubl.) JFB Pastore & JR Abbott		herb
RHAMNACEAE		
Sarcomphalus joazeiro (Mart.) Hauenschild	juazeiro	tree
RUBIACEAE		
Borreria scabiosoides Cham. & Schltdl.		herb
Richardia grandiflora (Cham. & Schltdl.) Steud.		herb
Hexasepalum teres (Walter) JH Kirkbr.		herb
SAPINDACEAE		
Cardiospermum corindum L.		climber
TURNERACEAE		
Turnera scabra Millsp.		herb
VERBENACEAE		
Lantoma canescens Kunth		shrub
Stachytarpheta coccinea Schauer		shrub
XIMENIACEAE		
Ximenia americana L.	ameixa	tree

*First time recorded specie in the State

**First time recorded specie in the Caatinga vegetation of Piauí

We identified ten pollination syndromes for the species, with a higher occurrence of melittophily (77%) and various small insects (DPI) (6%), associated with the most frequent attributes of yellow or white flowers, with nectar-like resources or nectar/pollen, traits associated with more general syndromes (Figure 2e). Silva et al. (2021), monitoring the comparative pollination service in the Caatinga area, also showed a predominance of species pollinated by bees (76.37% of the species), followed by chiropterophily and ornithophily, totaling 20%.

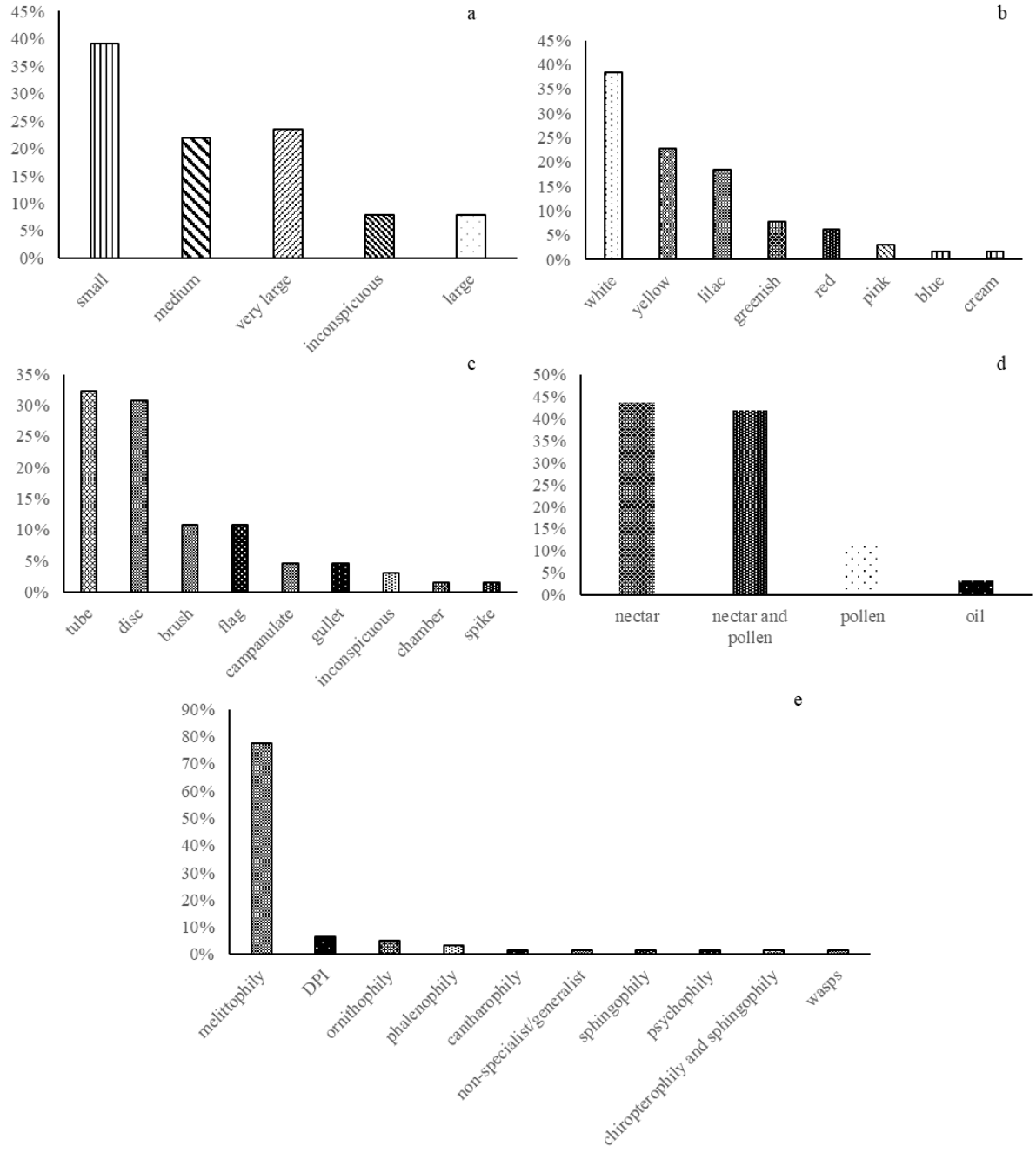

Figure 2. Floral traits of species close to apiaries in the Caatinga vegetation of Fartura do Piauí, microregion of São Raimundo Nonato – PI, Brazil. (a) floral size; (b) floral color; (c) floral type; (d) floral resource; (e) pollination syndrome (source: research archive).

In another study, Quirino and Machado (2014) found melittophily with 65.2% representation, as well as yellow flowers as the second most present (19.5%) also in a Caatinga area. Machado and Lopes (2004) also recorded yellow flowers more frequently (25.0%) followed by white ones (22.2%), but in terms of the resources of nectar and pollen, they present a very low percentage (nectar

and pollen 2.8%) compared to that found in our study, in addition to a higher frequency of specialized syndromes. This is probably a result of a greater number of recorded species, 147 in total, more than twice the richness we found. However, this work considers three large areas of Caatinga, which explains this greater number of species and diversity of syndromes. On the other hand, in fact, we recorded the same syndromes, except for anemophily, in a much smaller area.

Flowering phenology and available floral resources - When comparing the phenology, we observed that ten species were in the flowering phase during the dry period and fifty-one species during the rainy season. This greater flowering intensity is associated with the higher precipitation rates recorded in these months (Figure 3a and 3b). Some species that flower in the dry season also show flowers in the rainy season. These include: *Spondias tuberosa* L (Anacardiaceae); *Cnidoscolus quercifolius* Pohl., *Cnidoscolus urniger* (Pax) Pax, *Jatropha mollissima* (Pohl.) Baill. (Euphorbiaceae); *Mimosa tenuiflora* (Willd.) Poir. (Fabaceae); *Sida* cff. (Malvaceae); *Cardiospermum corindum* L (Sapindaceae). All of these are melittophilous, except for *Jatropha mollissima* (Pohl.) Baill, a species pollinated by hummingbirds. A study by Quirino and Machado (2014), in an area of Caatinga, shows melittophilous species flowering throughout the year, with two peaks – one during the rainy season and the other during the dry season. Most species (66.7%) peak during the rainy season or transition, while the other species (33.3%) peak during the dry season.

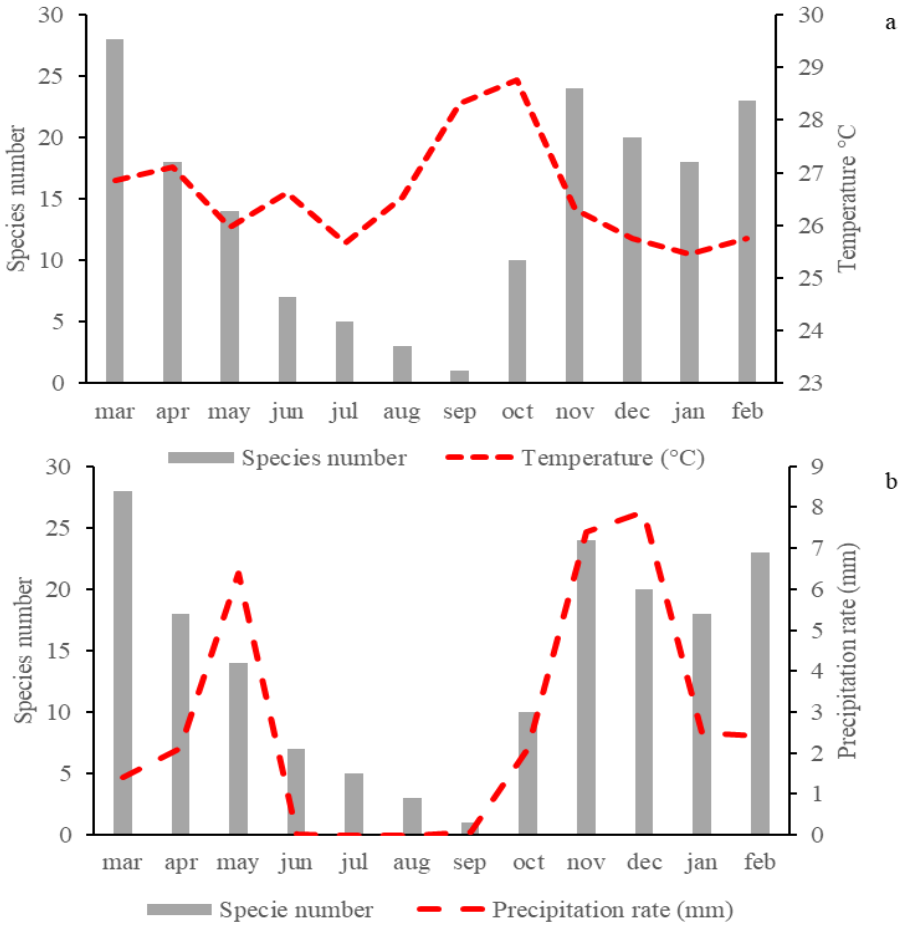

Figure 3. Flowering species of Caatinga, during the period from March/2021 to February/2022 in the municipality of Fartura do Piauí, Piauí, Brazil, related to monthly precipitation levels (a) and historical average temperature (b). (source: research arquive).

The month of March had the highest number of flowering species and September had the lowest, with only one flowering species, *Spondias tuberosa* L., typical species of Caatinga dry forest and important fountain for pollinator foraging during this period. Nadia et al. (2007) confirms this in their study on the pollination of the species, which is melittophilous and has a high frequency of floral visitors. Regarding phenology, these same authors record that the species flourishes at the end of the dry season and beginning of the rainy season, like we recorded in the monitored area.

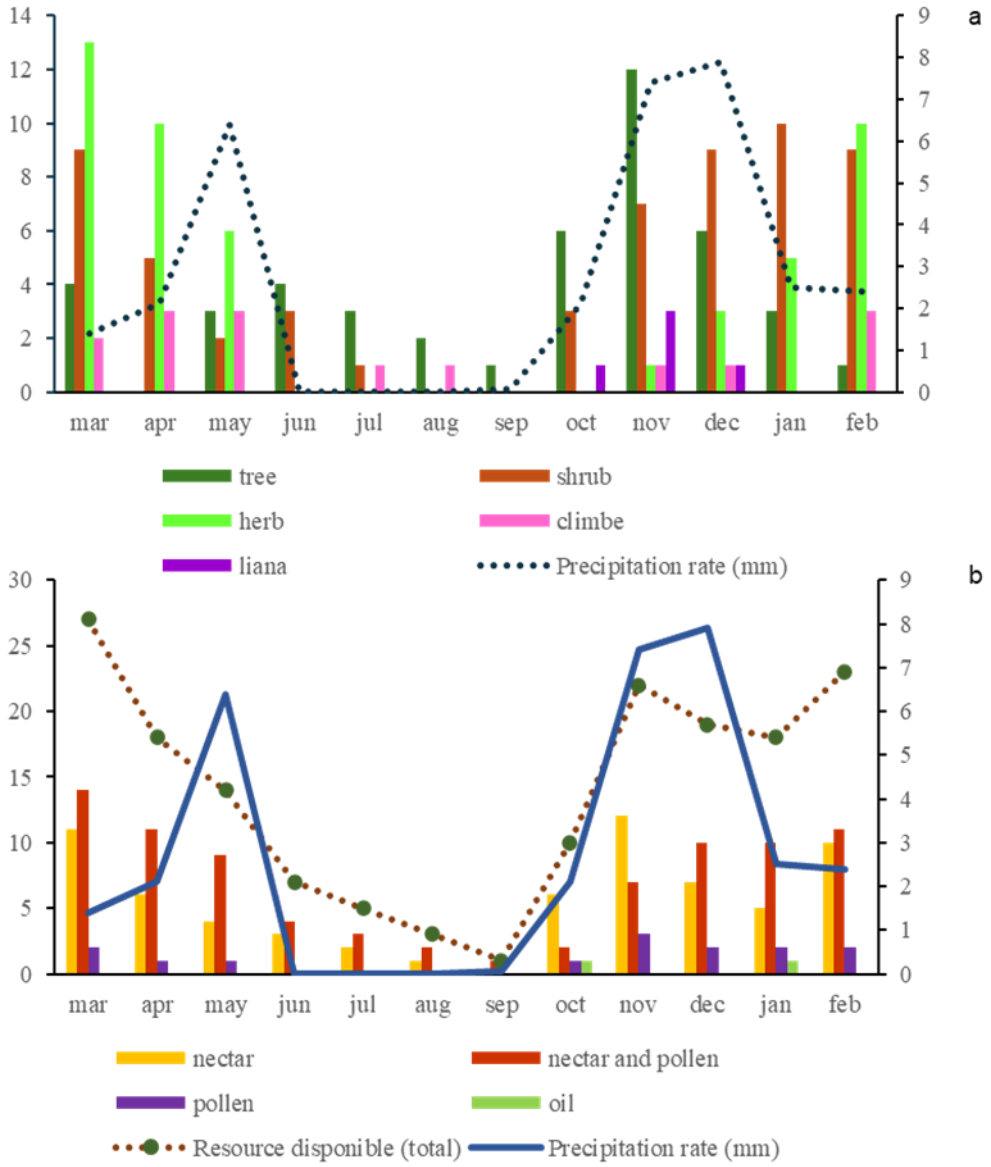

Figure 4. Precipitation rates per month versus life form (a) and floral resources (b) of the Caatinga species, from March/2021 to February/2022, municipality of Fortuna do Piauí, Piauí, Brazil (source: research archive).

With the lower precipitation rates at the end of the rainy season and during all the dry season, flowering tree species were more representative. These include: *Amburana cearensis* (Allemão) A.C.Sm (Amburana de Cheiro); *Astronium urundeuva* (Allemão) Engl. (Aroeira); *Cnidoscolus quercifolius* Pohl. (Slum); Cordia trichotoma (Vell.); *Lachesiodendron viridiflorum* (Kunth); *Luetzelburgia auriculata* (German) Ducke; *Mimosa tenuiflora* (Willd.); *Spondias tuberosa* L. (Umbuzeiro), *Sarcomphalus joazeiro* (Mart.) (Joazeiro), with a shrubby habit: *Cnidoscolus urniger* (Pax) Pax; *Sida* cff and *Jatropha mollissima* (Pohl.) Baill., the latter, flowering almost throughout the year. Some herbaceous species and vines have more persistent flowering for 3 months after the end of the rainy season, such as *Cardiospermum corindum* L. (Trepadeira), and herbaceous plants represented by *Alternanthera brasiliana* (L.) Kuntze, *Centratherum punctatum*, and *Pavonia cancellata*

(L.) (Figure 4.a), as already observed by Lopes et al., (2016).

Most of our herbaceous species flower quickly and are only found during the rainy season. Oliveira et al. (2017) confirm this in their work, concluding that in the period with less precipitation there was a decrease in flowering, but tree species still represented the phenophase in the dry period. Besides this, these life forms are still important in beekeeping pastures, even with many flowerings only during the rainy season or when torrential rains occur, because of the offer of food resources, such as nectar and pollen, at least for a short time (Camara et al., 2021; Morais et al., 2020; Reis et al., 2006). In addition to this, these species represent at least 40% of the total number of plants visited by bees (Lorenzon et al., 2003).

The period between July and September did not register any precipitation, but flowering species were found in the plots offering nectar and nectar/pollen (Table 2; Figure 4.b), and as was expected, most species (9) are melittophilous or pollinated by several small insects (DPI), with these also offering pollen (Brasil and Guimarães-Brasil, 2018).

floral shapes, types and resources accessible to *Apis mellifera*. The exception, the species *Jatropha mollisima*, which is pollinated by hummingbirds, has disc-shaped flowers that are easily accessible to bees. This data confirms our hypothesis and can guide beekeepers to avoid cutting and burning in areas with the presence of these species, ensuring bee pasture in the months with lower rainfall. These floral resources can constitute a complete diet during all phases of bee development and together, they provide proteins, carbohydrates, vitamins, mineral salts, and fats, thus being the basis of the nutrition of these insects (Freitas and Silva 2006). In the Caatinga, there are several species of plants that produce nectar even in the driest periods of the year (*e.g*. *Astronium urundeuva, Spondias tuberosa, Cnidoscolus quercifolius, Jatropha mollissima, Croton sonderianus, Anadenanthera colubrina, Pityrocarpa moniliformis*), among others, some of

Table 2. Flowering species and their resources, in the dry period from June to September (2021) in the Caatinga area of Fortuna do Piauí, Piauí, Brazil.

Family/Species	Life form	Resource	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	jan	feb
ANACARDIACEAE														
Astronium urundeuva (Allemão) Engl.	tree	nectar	-	-	-	X	X	-	-	-	-	-	-	-
Spondias tuberosa L.	tree	nectar and pollen	-	-	-	-	-	X	X	X	-	-	-	-
EUPHORBIACEAE														
Cnidoscolus quercifolius Pohl.	tree	nectar and pollen	X	X	-	X	X	-	-	-	X	X	X	X
Cnidoscolus urniger (Pax) Pax	shrub	nectar	-	-	X	X	X	-	-	-	X	X	X	-
Jatropha mollissima (pohl.) Baill.	shrub	nectar	X	X	X	X	-	-	-	X	X	X	X	X
FABACEAE														
Lachesiodendron viridiflorum (Kunth) PG Ribeiro, LP Queiroz & Luckow	tree	nectar	-	-	-	-	-	X	-	-	-	-	-	-
Luetzelburgia auriculata (Allemão Ducke)	tree	nectar and pollen	-	-	-	-	X	-	-	-	-	-	-	-
Mimosa tenuiflora (Willd.) Poir.	tree	nectar and pollen	X	-	-	X	X	-	-	X	X	-	-	X
MALVACEAE														
Sida cff.	shrub	nectar and pollen	X	X	X	X	-	-	-	-	-	-	-	X
SAPINDACEAE														
Cardiospermum corindum L.	climb	nectar and pollen	-	X	X	-	X	X	-	-	X	X	-	X

In addition to the bee pasture and floral resources available to *Apis mellifera* L. bees, we also considered species that offered shade during the dry period, such as *Lachesiodendron viridiflorum*, which remained with leaves throughout the dry season, together with *Sarcomphalus joazeiro*, *Aspidosperma pyrifolium*, which show a slow and late decline compared to the other species

observed, presenting themselves as ideal for shading strategies when choosing locations for implementing apiaries. Deciduousness is not the same for all Caatinga species (Amorim et al., 2009), as leaf fall depends not only on rainfall, but also on the water reserve in the soil, which can prolong availability for plants for different periods, creating greater variability (Jolly and Running, 2004). Amorin et al. (2009) considers the conservation of places with a greater diversity of woody species to be important for the use of resources in apiaries.

Regarding the diversity we found, we believe that few species are recognized by beekeepers as food sources for the bees. Câmara et al. (2021) confirm this assertion through interviews carried out in Rio Grande do Norte, Northeast of Brazil, with these workers. Our work also helps with part of the recommendations for the beekeeper, which includes, in addition to appropriate management of their hives, identifying the occurrence of polliniferous and nectariferous resources around the apiaries (Grado et al., 2024; Modro et al., 2011), knowing the flowering cycles of plant species of an area, tracing the annual availability profile of floral resources, such as nectar and pollen for bees (Freitas and Silva, 2006), which our research provided. We also indicate here the need for better guidance for beekeepers, so that they can position apiaries in the vicinity of these species or avoid cutting and burning them during the drought, reducing the need for feed during the period. Studies on germination and multiplication of these species, especially the key ones who are still flowering in the dry period, may also be necessary to produce seedlings.

Conclusions

Our work identified species occurring in the Caatinga, increasing knowledge about their distribution, and highlighting new records related to transition areas or ecotonal regions of the ecosystem. When analyzing floral characters and pollination syndromes, we also identified ecological patterns associated with the vegetation, such as higher frequencies of floral attributes related to melittophily and more general pollination syndromes. The identification of floral resources, as well as the monitoring of the flowering phenology of the species, allowed the identification of those with available during the dry season in the Caatinga.

In addition to floral resources, we identified another available resource, shading, made possible by the species *Lachesiodendron viridiflorum*, which retained its leaves throughout the dry season. This was also observed in *Sarcomphalus joazeiro* and *Aspidosperma pyrifolium*, which have a slower leaf fall. These species provide an alternative for the implementation of focal points in apiaries. The analyses carried out in this work can provide better guidance for beekeepers regarding the positioning of apiaries, ideally close to areas with identified species. This can also incentivize biological conservation by demonstrating that the preservation of these species can reduce the need for artificial feed during the dry period in the Caatinga. Further research on seed germination and multiplication of these species will be necessary for better planning of beekeeping pasture and organic honey production.

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