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Original article

Floristic characterization and pollen morphology of plants visited by *Apis mellifera* L. in caatinga areas in Bahia, Brazil

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ABSTRACT

The aim of this study was to identify plant species visited by *Apis mellifera* L. in honey producing areas with typical Caatinga vegetation in the State of Bahia, as well as morphologically characterize pollen grains of the most representative species. Flowering specimens were collected from both areas, herborized, identified and deposited at the HUNEB herbarium. Analyses of floristic similarities were performed between eleven municipalities close to the study areas. Pollen was collected from all specimens, acetolyzed, measured, statistically analyzed, morphologically described, and photographed in light microscopy. Of the total of species recorded, 67.46 % were regarded as having beekeeping importance, with the richest botanical families being Fabaceae, Malvaceae and Asteraceae. Additionally, 37.5 % of the recorded species were herbs. The analyzed municipalities showed 84 % of floristic similarity. Of the total species recorded with visits by *A. mellifera*, 25.52 % had their pollen grains already described in the literature as monads, tetrads and polyads; isopolar, apolar and heteropolar; and mostly prolate spheroidal shape. Sizes varied from small to large, and the amb circular was predominant. The exine ornamentation was greatly diversified, varying from psilate to echinate. The obtained data corroborate the palynological knowledge of plants regarded as having beekeeping importance within the Caatinga.

Keywords: Floristic similarity, honeybee flora, pollen grains, palynology, semiarid.

Introduction

Northeast Brazil is known for its areas with great beekeeping potential due to the diversity of environments and native Caatinga flora, especially in the State of Bahia, a biome distributed through 70 % of this region (Sena 2011; Oliveira & Santos 2014; Liberato & Morais 2016). According to data obtained by Instituto Brasileiro de Geografia e Estatística (IBGE 2021), in 2021, the production of honey in Brazil had an increase of 6.4 % more than the previous year, and the Northeast was one of the three regions that

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boosted this growth, participating with 36.3 % of the national production, estimated in 55.8 thousand tons. In this scenario, the state of Bahia stands out occupying the fifth place in the honey production ranking, accounting for 8.2 % of the Brazilian honey produced in 2021.

Nonetheless, for beekeepers to have an ideal use of quality and production of honey in a specific region, it is necessary to know the favourable flora for bees, besides analysing the soil, local climate, and support capacity of this region (Pereira *et al.* 2006; Santos & Ribeiro 2009; Ribeiro *et al.* 2019). Plants with beekeeping potential usually show intense flowering events, being attractive food sources for different species of bees. These plant species might show floral morphological characteristics, besides specific odours, that enable pollinator attraction, being the researcher or beekeeper's job to infer their utility for bees (Freitas & Silva 2006; Santos *et al.* 2006a; Melo *et al.* 2018).

The biological knowledge of plant species is important for beekeeping as flowering times, and pollen morphology helps to estimate the beekeeping potential of these species from the bee pasture and contribute to the creation of a flowering calendar for local bee plants (Freitas & Silva 2006; Lima *et al.* 2006; Pereira *et al.* 2006; Moreti *et al.* 2007). Studies on the floristic diversity of interest to bees allow the creation of future strategies to rationally use the beekeeping flora and the conservation of their ecosystems, contributing to a possible production increase of honey (Mendonça *et al.* 2008).

Several floristic studies have revealed the rich diversity and structure of the Caatinga biome (Araújo *et al.* 2010; Santos *et al.* 2011; Lima *et al.* 2012; Sanquetta *et al.* 2014; Luna *et al.* 2015; Rocha *et al.* 2017), as well as studies focusing on bee plant species for the Caatinga and other ecosystems. The description of pollen morphology from these areas, coupled with palynological analyses of bee products, has contributed to the identification of plant species foraged by bees, including the species *Apis mellifera* L. (Ferguson & Skvarla 1982; Aguiar *et al.* 2002; Almeida *et al.* 2006; Lima *et al.* 2006; Viana *et al.* 2006; Almeida 2007; Chaves *et al.* 2007; Vidal *et al.* 2008; Oliveira *et al.* 2010; Nascimento *et al.* 2014; Silva *et al.* 2014a; Silva *et al.* 2016b; Costa *et al.* 2018; Rasoloarijao *et al.* 2019; Mander *et al.* 2020; Moraes *et al.* 2020; Silva *et al.* 2020; Lu *et al.* 2021; Reis *et al.* 2021; Dias *et al.* 2022). *A. mellifera* forages to flowers for both pollen and nectar. The species' preference for floral types and available resources can be altered by several factors, including the period of the year, available flowering in the surrounding area, and the nutritional needs of the colony. In addition, these bees may have their foraging behavior modified as a function of temperature, but this is not a limiting factor for the species (Malerbo-Souza & Silva 2011; Moura *et al.* 2011; Araújo *et al.* 2014).

Thus, the aim of this study was to conduct a floristic study in two areas of Caatinga vegetation to characterize bee plant species, especially for colonies of *A. mellifera*, in apiaries located in the State of Bahia, as well as morphologically characterize pollen grains of the most representative species.

Material and methods

Study area

The bee flora was sampled from an area of native Caatinga vegetation with surrounding crops near the Caldeirão do Mulato and Roça da Fonte apiaries in the municipalities of Antônio Gonçalves (12º26'07"S; 39º07'11"W; altitude 191 m) and Campo Formoso (10º30'27"S; 40º19'17"W; altitude 556 m), respectively. These municipalities are located in the Mid-Northern semiarid region of the State of Bahia (Fig. 1), near the plains of the Jacaré and Salitre rivers in the Jacobina mountain complex (SEI 2020).

The climate in these municipalities varies from subhumid to dry (Antônio Gonçalves) and semiarid (Campo Formoso), with mean temperatures from 14.5 ºC to 33 ºC, and rainfall varying from 500 to 1,100 mm, annually. The vegetation from this region is diverse and adapted to scarce rainfall, being dense to sparse typical arboreal Caatinga with a gramineous herbaceous layer. The municipality of Antônio Gonçalves is characterized by a mosaic of Caatinga-dry forest-cerrado, while Campo Formoso is characterized by open to dense arboreal Caatinga and remnants of Atlantic rainforest (SEI 2020).

Collection and processing of botanical specimens

Specimen collection visited by *A. mellifera* was performed from September 2016 to May 2017 and from October 2019 to January 2020 at Antônio Gonçalves, while at Campo Formoso, specimen collection only took place from May 2019 to January 2020. All specimens were monthly collected in both municipalities based on the direct observation of *A. mellifera* foraging their flowers, with a duration of five minutes. All field collections were performed from eight to nine hours per day, considering the vegetation layers of trees, shrubs, subshrubs, herbs and lianas (Rizzini & Rizzini 1983). Specimen collection took place on random pre-existent trails surrounding the study areas in a ray of 1,500 m (Marques *et al.* 2011) from Caldeirão do Mulato and Roça da Fonte apiaries. Flowering specimens were collected using usual botanical techniques (Bridson & Forman 1998), annotating floral attributes such as colour, attraction unit, symmetry, size, and odour presence (Percival 1965) to aid in specimen characterization, mostly for identification and labelling purposes. All identifications were based on comparisons between specimens deposited at Herbarium of the Universidade do Estado da Bahia (HUNEB) and Herbarium of the Universidade Estadual de Feira de Santana (HUEFS), using identification keys from the specialized literature, and by sending duplicates to taxonomic specialists. The classification system adopted in

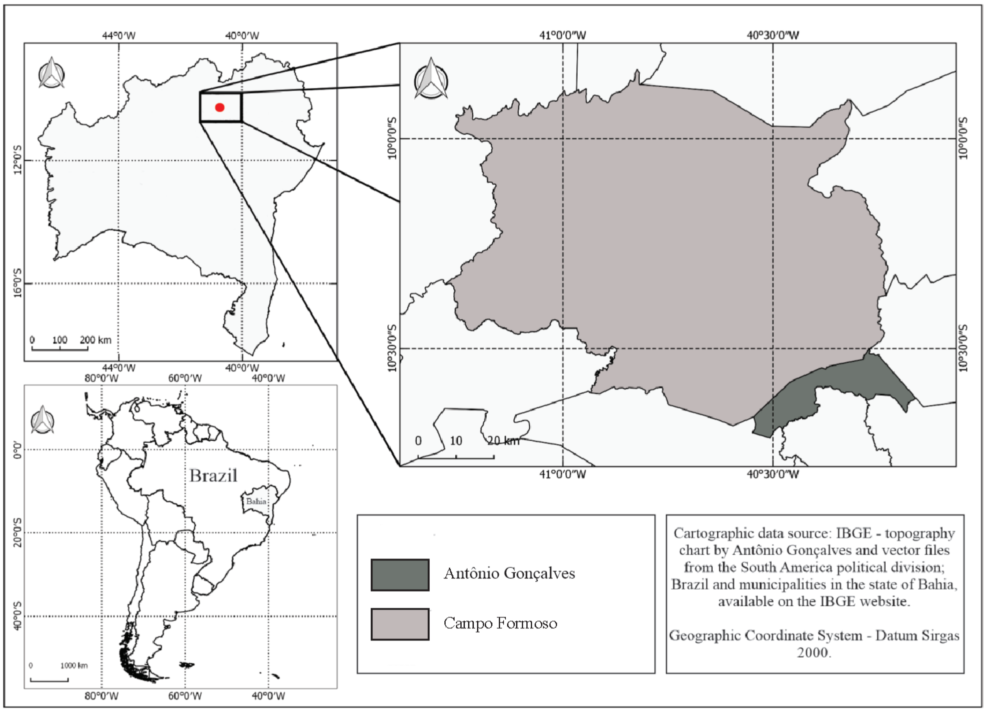

Figure 1. Map showing the location of Antônio Gonçalves and Campo Formoso municipalities, State of Bahia, Brazil. Source: Adaptaded from Reis *et al.* (2021).

this study was the Angiosperm Phylogenetic Group IV (The Angiosperm Phylogeny Group *et al.* 2016), and specimens were deposited at the HUNEB herbarium.

The determination of plant species with beekeeping importance was made through direct observations of bee foraging in the field and also based on the literature (Aguiar *et al.* 2002; Pereira *et al.* 2006; Santos *et al.* 2006b; Vidal *et al.* 2008; Marques *et al.* 2011; Maia-Silva *et al.* 2012; Nascimento *et al.* 2014; Silva *et al.* 2014b; Salis *et al.* 2015; Salis *et al.* 2017). Plant species with beekeeping importance were identified and grouped into a checklist with their respective floral resources (pollen/nectar/oil) identified based on the specialized literature (Pedro & Camargo 1991; Oliveira *et al.* 1998; Aguiar *et al.* 2002; Agostini & Sazima 2003; Aguiar *et al.* 2003; Costa *et al.* 2006; Machado & Lopes 2006; Pereira *et al.* 2006; Santos *et al.* 2006a; Santos *et al.* 2006b; Viana *et al.* 2006; Polatto *et al.* 2007; Silva *et al.* 2007; Vidal *et al.* 2008; Mendonça *et al.* 2008; Ramalho & Rosa 2010; Modro *et al.* 2011; Moreira & Bragança 2011; Maia-Silva *et al.* 2012; Nascimento *et al.* 2014; Silva *et al.* 2014a; Costa *et al.* 2015; Salis *et al.* 2015, 2017; Saturni *et al.* 2015; Guimarães-Brasil *et al.* 2017; Melo 2019; Pinto 2019; RCPol 2021). The flowering period was determined based on field observation within the sampling period. Common names of plant species with beekeeping importance were determined based on information provided by beekeepers and local citizens and subsidized by specialized literature (Silva *et al.* 2014c; Souza & Lorenzi 2019).

Monthly rainfall estimates were retrieved for both municipalities based on the data from the INMET (2020) website for all periods of our field studies: Antônio Gonçalves (2016-2017) and Campo Formoso (2019-2020). A floristic similarity analysis was performed between the bee flora from the studied municipalities with other areas of Caatinga vegetation in the Brazilian semiarid (Table 1). The checklist was used to elaborate a binary matrix of absence/presence for all species compiled from our fieldwork and the selected studies from the Brazilian semiarid to observe floristic similarity patterns in these areas. Subsequently, the Unweighted Pair Groups Method Average (UPGMA) was used as the weighted average algorithm to identify the floristic relationship between the studied areas. A dendrogram generated from a cluster analysis using the Jaccard index was generated, alongside all analyses, using the PC-ORD 7.0 software (Mccune & Mefford 2011).

Collection and processing of pollen material for the morpho-pollinic study

All pollinic studies were developed at the Laboratório de Estudos Palinológicos (LAEP) from the Universidade do Estado da Bahia (UNEB), *Campus* VII, Senhor do Bonfim, Bahia. Pollen samples (flowers/floral buds) were obtained from exsiccates deposited at the HUNEB herbarium from our field studies and selected based on occurring at least in three municipalities from the floristic similarity analysis. Most pollen grains were acetolyzed, according to Erdtman (1960), but for fragile pollen grains, we used the ACLAC method

Table 1. Location of all areas used in the floristic similarity analysis.

Papers	Location (Brazil)
Santos *et al*. (2006)	Petrolina, Pernambuco
Chaves *et al*. (2007)	Cocal, Piauí
Benevides & Carvalho (2009)	Caraúbas, Rio Grande do Norte
Nascimento *et al*. (2014)	Cruz das Almas, Bahia
Silva *et al*. (2014b)	Jaicós and Massapê do Piauí, Piauí
Costa *et al*. (2018)	Prata, Paraíba
Silva *et al*. (2018)	Aparecida, Paraíba
Moraes *et al*. (2020)	São João do Piauí, Piauí
Silva *et al*. (2020)	São José do Bonfim, Paraíba

(Raynal & Raynal 1971). Pollen grains were mounted using slides and coverslips with glycerine gelatine, sealed with paraffin, and analyzed and measured within seven days after mounting using a light microscope.

A total of 25 pollen grains were randomly analyzed for each specimen following technical recommendations by Salgado-Labouriau (1973) and Melhem *et al.* (1974). Morphometrical parameters such as polar axis (PA) and equatorial diameter (ED) in equatorial view were also analyzed. For other measurements (apocolpium side, aperture, spine distance, height and diameter of the base of spines, subspinal sexine elevation, sexine and nexine thickness), only ten pollen grains were randomly analyzed. PA and ED values of echinate pollen grains were measured from the subspinal sexine elevation. In other words, the diameter and height of spines were disregarded. For apolar pollen grains, a single measurement was done for the diameter. Alternatively, the longest (LD) and smallest (SD) diameters were measured for tetrads and polyads.

Quantitative data for 25 samples were statistically analyzed using the arithmetic average ($\overline{x}$), sample deviation (σ), mean standard deviation (S), coefficient of variability (CV), the 95 % confidence interval (CI), and the range (R). In contrast, for measurements from 10 to smaller than 25 samples, only the arithmetic average was calculated.

Pollen grains from all studies species were illustrated based on photomicrographs obtained from a digital camera coupled with a Zeiss® Axioskop *plus* microscope. Morphological descriptions included characters related to size, shape, polarity, aperture type, and exine structure and ornamentation. The terminology used in this study follows Punt *et al.* (2007) and Barth & Melhem (1988).

Results

Diversity of the bee flora

The flora from the municipalities of Antônio Gonçalves and Campo Formoso in the State of Bahia was represented by 126 flowering species within the studied period. Among the identified species, 85 (67.46 %) were regarded as having beekeeping importance, distributed in 66 genera and 31 botanical families (Table 2, Fig. 2). For the municipality of Antônio Gonçalves, all plant species with beekeeping importance were collected from September 2016 to May 2017, with no records observed for the period from October 2019 to January 2020.

The botanical families with the largest number of bee plant species recorded were Fabaceae (21.17 %), Malvaceae (12.94 %), Asteraceae (9.41 %), Euphorbiaceae (7.05 %), Rubiaceae (4.70 %), Anacardiaceae and Verbenaceae (3.52 %, each), followed by Amaranthaceae, Apocynaceae, Bignoniaceae, Boraginaceae, Convolvulaceae, Malpighiaceae, Passifloraceae and Solanaceae (2.35 %, each) (Table 2).

The Caatinga native and endemic plant species with beekeeping importance recorded for our study areas were: *Anadenanthera colubrina* (Vell.) Brenan, *Borreria verticillata* (L.) G.Mey., *Colicodendron yco* Mart., *Croton jacobinensis* Baill., *Herissantia crispa* (L.) Brizicky, *H. tiubae* (K.Schum.) Brizicky, *Mimosa tenuiflora* (Willd.) Poir., *Pavonia cancellate* (L.) Cav., *P. martii* Colla, *Peltophorum dubium* (Spreng.) Taub., *Senna aversiflora* (Herb.) H.S.Irwin & Barneby, *Sida galheirensis* Ulbr., and *Solanum paniculatum* L. Additionally, native and cultivated fruit species (*i.e.*, *Anacardium occidentale* L., *Mangifera indica* L., *Passiflora foetida* L., and *Psidium guajava* L.) and ornamental species (*i.e.*, *Tecoma stans* (L.) Juss. ex Kunth and *Antigonon leptopus* Hook. & Arn.) were also foraged by *Apis mellifera*.

The species *Alternanthera brasiliana* (L.) Kuntze (Amaranthaceae), *A. colubrina* (Fabaceae), *Melochia tomentosa* L. (Malvaceae), *M. tenuiflora* and *Senegalia bahiensis* (Benth.) Seigler & Ebinger (Fabaceae) flowered during a period without any rainfall from December (2016) to February (2017) in the municipality of Antônio Gonçalves (Fig. 3). Even though this period is well known for the lack of rainfall, it is characterized by the relatively high diversity of bee plants flowering being visited by bees.

For example, in the municipality of Campo Formoso, the species *A. leptopus* (Polygonaceae) and *Centratherum punctatum* Cass. (Asteraceae) flowered both in the low and heavy rainfall periods from May (2019) to January (2020)

Table 2. Bee flora foraged by *Apis mellifera* L. in the municipalities of Antônio Gonçalves and Campo Formoso, State of Bahia, Brazil. Antônio Gonçalves (AG); Campo Formoso (CF); presence (+); absence (–); herbs (Her); shrubs (Shru); subshrubs (Sub); Lianas (Lia); flowering period (FP); floral resource offered (RO); pollen (P); nectar (N); oil (O).

Family/Species	Voucher	Municipalities		Common Name	Habit	FP	RO	Reference
		AG	CF					
Acanthaceae								
Ruellia bahiensis (Nees) Morong	Reis, H.S. 138	+	+	Folha-de-mocó	Her	Sep-Jan	N/P	Nascimento *et al.* (2014)
Amaranthaceae								
Alternanthera brasiliana (L.) Kuntze	Reis, H.S. 117	+	+	Ervanço	Her	Sep-Jan	N	Pereira *et al.* (2006)
Gomphrena gardneri Moq.	Reis, H.S. 134	–	+	Perpétua	Her	Nov-Dec	N	Salis *et al.* (2015)
Anacardiaceae								
Anacardium occidentale L.	Reis, H.S. 122	–	+	Cajueiro	Tree	Oct-Dec	N/P	Santos FAR *et al.* (2006)
Mangifera indica L.	Reis, H.S. 113	–	+	Mangueira	Tree	Sep-Nov	N	Salis *et al.* (2015)
Tapirira guianensis Aubl.	Reis, H.S. 145	–	+	Pau-pombo	Tree	Dec-Jan	N	Viana *et al.* (2006)
Apocynaceae								
Calotropis procera (Aiton) W.T.Aiton	Reis, H.S. 47	+	–	Algodão-de-seda	Shru	Dec-Jan	N	Salis *et al.* (2017)
Tabernaemontana laeta Mart.	Reis, H.S. 125	–	+	Jasmim-de-leite	Tree	Sep-Nov	N	Pinto (2019)
Arecaceae								
Syagrus coronata (Mart.) Becc.	Reis, H.S. 148	+	+	Licuri	Tree	Jan-Dec	N	Nascimento *et al.* (2014)
Asteraceae								
Acmella uliginosa (Sw.) Cass.	Reis, H.S. 91	–	+	Agrião-bravo	Her	July-Aug	P	RCPol (2021)
Centratherum punctatum Cass.	Reis, H.S. 99	+	+	Suspiro	Her	July-Jan	N	Santos FR *et al.* (2006)
Conocliniopsis prasiifolia (DC.) R.M.King & H.Rob.	Reis, H.S. 102	+	+	Mentrasto	Sub	May-Aug	N	Costa *et al.* (2015)
Cosmos sulphureus Cav.	Reis, H.S. 131	–	+	Cosmo-amarelo	Her	Oct-Jan	P	Vidal *et al.* (2008)
Emilia fosbergii Nicolson	Reis, H.S. 89	–	+	Algodão-de-preá	Her	July	P	Moreira & Bragança (2011)
Lepidaploa chalybaea (Mart. ex DC.) H.Rob.	Reis, H.S. 03	+	–	Vassourinha	Sub	Sep-May	N	Nascimento *et al.* (2014)
Tridax procumbens L.	Reis, H.S. 121	+	+	Erva-de-touro	Her	Feb-Aug-Oct	N/P	Moreira & Bragança (2011)
Vernonanthura ferruginea (Less.) H.Rob.	Reis, H.S. 114	–	+	Assa-peixe	Tree	Sep-Oct	N	Pedro & Camargo (1991)
Bignoniaceae								
Pyrostegia venusta (Ker Gawl.) Miers	Reis, H.S. 101	–	+	Cipó-de-são-joão	Lia	Aug	N/P	Mendonça *et al.* (2008); Pollato *et al.* (2007)
Tecoma stans (L.) Juss. ex Kunth	Reis, H.S. 126	–	+	Ipê-de-jardim	Tree	Oct-Dec	N/P	Silva *et al.* (2007)
Boraginaceae								
Heliotropium angiospermum Murray	Reis, H.S. 130	+	–	Crista-de-galo	Her	Sep-Jan	N	Nascimento *et al.* (2014)
H. indicum L.	Reis, H.S. 69	+	+	Cravo-de-urubu	Her	Oct	N/P	Moreira & Bragança (2011)

Table 2. Cont.

Family/Species	Voucher	Municipalities		Common Name	Habit	FP	RO	Reference
		AG	CF					
Capparaceae								
Colicodendron yco Mart.	Reis, H.S. 21	+	−	Icó	Shru	Dec	N/P	Aguiar *et al*. (2002)
Commelinaceae								
Commelina erecta L.	Reis, H.S. 110	+	+	Santa-luzia	Her	May-Aug	N	Maia-Silva *et al*. (2012)
Convolvulaceae								
Ipomoea incarnata (Vahl) Choisy	Reis, H.S. 02	+	−	Jetirana	Lia	Sep	N	Salis *et al*. (2015)
Jacquemontia martii Choisy	Reis, H.S. 116	−	+	Corda-de-viola	Lia	Sep	N	Salis *et al*. (2017)
Cucurbitaceae								
Momordica charantia L.	Reis, H.S. 109	+	+	Melão-de-são-caetano	Lia	Aug-Jan	N/P	Salis *et al*. (2015)
Euphorbiaceae								
Cnidoscolus obtusifolius Pohl ex Baill.	Reis, H.S. 54	+	−	Cansanção	Shru	Apr	N	Maia-Silva *et al*. (2012)
C. urens (L.) Arthur.	Reis, H.S. 27	+	−	Urtiga	Sub	Nov-Feb	N	Maia-Silva *et al*. (2012)
Croton heliotropiifolius Kunth	Reis, H.S. 73	+	−	Marmeleiro	Sub	Nov	N/P	Guimarães-Brasil *et al*. (2017)
C. jacobinensis Baill.	Reis, H.S. 111	+	+	Marmeleiro	Sub	Aug-Dec	N/P	Pereira *et al*. (2006)
C. tetradenius Baill.	Reis, H.S. 77	+	−	Caatinga-de-bode	Sub	Jan-Feb	N/P	Machado & Lopes (2006)
Ricinus communis L.	Reis, H.S. 120	−	+	Mamona	Shru	Oct-Nov	N/P	Nascimento *et al*. (2014)
Fabaceae								
Anadenanthera colubrina (Vell.) Brenan	Reis, H.S. 26	+	−	Angico	Tree	Dec	N/P	Pereira *et al*. (2006)
Caesalpinia pulcherrima (L.) Sw.	Reis, H.S. 132	−	+	Flamboyanzinho	Tree	Oct	N	Silva *et al*. (2014a)
Chamaecrista flexuosa (L.) Greene	Reis, H.S. 136	−	+	Peninha	Her	July	N	Moreira & Bragança (2011)
C. nictitans (L.) Moench	Reis, H.S. 98	−	+	Falsa-dormideira	Her	Nov	P	Aguiar *et al*. (2003)
Inga edulis Mart.	Reis, H.S. 128	−	+	Ingá-cipó	Tree	Oct-Dec	P	Modro *et al*. (2011)
Macroptilium bracteatum (Nees & Mart.) Maréchal & Baudet	Reis, H.S. 44	+	−	Orelha-de-onça	Her	Jan	N	Salis *et al*. (2015)
Mimosa candollei R.Grether	Reis, H.S. 45	+	−	Malícia	Her	Jan-May	N/P	Maia-Silva *et al*. (2012)
M. pudica L.	Reis, H.S. 108	−	+	Dormideira	Her	Aug	N/P	Pereira *et al*. (2006)
M. tenuiflora (Willd.) Poir.	Reis, H.S. 68	+	−	Jurema-preta	Tree	Sep-Oct	N/P	Pereira *et al*. (2006)
Peltophorum dubium (Spreng.) Taub.	Reis, H.S. 140	+	+	Angico-amarelo	Tree	Dec-Jan	N	Salis *et al*. (2015)
Periandra coccinea (Schrad.) Benth.	Reis, H.S. 84	−	+	Cassia	Lia	June	N/P	Agostini & Sazima (2003)
Senegalia bahiensis (Benth.) Seigler & Ebinger	Reis, H.S. 43	+	−	Coração-de-mulata	Tree	Jan	N	Pereira *et al*. (2006)
S. polyphylla (DC.) Britton & Rose	Reis, H.S. 149	−	+	Espinheiro	Tree	Dec	N/P	Maia-Silva *et al*. (2012)

Table 2. Cont.

Family/Species	Voucher	Municipalities		Common Name	Habit	FP	RO	Reference
		AG	CF					
Senna aversiflora (Herb.) H.S.Irwin & Barneby	Reis, H.S. 107	−	+	São-joão	Shru	Aug	P	Aguiar *et al.* (2003)
S. occidentalis (L.) Link	Reis, H.S. 46	+	−	Fedegoso	Shru	Jan	P	Maia-Silva *et al.* (2012)
S. rugosa (G.Don) H.S.Irwin & Barneby	Reis, H.S. 95	−	+	Amarelinho	Shru	May-July	P	Aguiar *et al.* (2003)
S. spectabilis (DC.) H.S.Irwin & Barneby	Reis, H.S. 39	+	−	São-joão	Tree	Jan	P	Nascimento *et al.* (2014)
Stylosanthes viscosa (L.) Sw.	Reis, H.S. 103	−	+	Estilosantes	Her	Aug	N	Ramalho & Rosa (2010)
Hypericaceae								
Vismia guianensis (Aubl.) Choisy	Reis, H.S. 152	−	+	Lacre-branco	Tree	Jan	N/P	Saturni *et al.* (2015)
Lamiaceae								
Ocimum campechianum Mill.	Reis, H.S 15	+	−	Manjericão-grande	Her	Nov-Dec	N	Nascimento *et al.* (2014)
Lythraceae								
Lagerstroemia indica L.	Reis, H.S. 139	−	+	Extremosa	Shru	Nov-Jan	N	Silva *et al.* (2014a)
Malpighiaceae								
Galphimia brasiliensis (L.) A.Juss.	Reis, H.S. 59	+	−	Trialis	Sub	Apr-May	P	Modro *et al.* (2011)
Stigmaphyllon paralias A.Juss.	Reis, H.S. 156	−	+	Erva-ereta	Her	Jan	O	Costa *et al.* (2006)
Malvaceae								
Corchorus hirtus L.	Reis, H.S. 119	−	+	Juta	Sub	Sep	P	Salis *et al.* (2015)
Herissantia crispa (L.) Brizicky	Reis, H.S. 01	+	−	Lava-prato	Her	Sep-Mar	N/P	Moreira & Bragança (2011)
H. tiubae (K.Schum.) Brizicky	Reis, H.S. 06	+	−	Mela-bode	Shru	Sep-Mar	P	Maia-Silva *et al.* (2012)
Melochia tomentosa L.	Reis, H.S. 04	+	−	Malvarisca	Shru	Jan-May	N	Santos FAR *et al.* (2006)
Pavonia cancellata (L.) Cav.	Reis, H.S. 133	+	+	Guanxuma-rasteira	Her	Oct-Nov	N/P	Maia-Silva *et al.* (2012)
P. malacophylla (Link & Otto) Garcke	Reis, H.S. 104	−	+	Malva-rosa	Shru	Aug	N/P	Oliveira *et al.* (1998)
P. martii Colla	Reis, H.S. 83	−	+	−	Her	June-July	P	Machado & Lopes (2006)
P. sidifolia Kunth	Reis, H.S. 48	+	−	Malva	Her	Jan	P	Moreira & Bragança (2011)
Sida cordifolia L.	Reis, H.S.	+	−	Malva-branca	Her	Dec	P	Pereira *et al.* (2006)
S. galheirensis Ulbr.	Reis, H. S. 70	+	−	Malva-roxa	Her	Oct	P	Machado & Lopes (2006)
Waltheria indica L.	Reis, H.S. 30	+	−	Malva	Her	Jan	N	Nascimento *et al.* (2014)
Melastomataceae								
Pterolepis trichotoma (Rottb.) Cogn.	Reis, H.S. 115	−	+	−	Her	Sep-Oct	P	Melo (2019)
Meliaceae								
Trichilia hirta L.	Reis, H.S. 66	+	−	Carrapeta	Tree	May	N	Salis *et al.* (2015)

Table 2. Cont.

Family/Species	Voucher	Municipalities		Common Name	Habit	FP	RO	Reference
		AG	CF					
Molluginaceae								
Mollugo verticillata L.	Reis, H.S. 36	+	–	Capim-tapete	Her	Feb-Mar	P	Costa *et al.* (2015)
Myrtaceae								
Psidium guajava L.	Reis, H.S. 123	–	+	Goiabeira	Tree	Oct-Jan	P	Santos FR *et al.* (2006)
Passifloraceae								
Passiflora cincinnata Mast.	Reis, H.S. 100	–	+	Maracujá-da-caatinga	Lia	July	N/P	Pereira *et al.* (2006)
P. foetida L.	Reis, H.S. 49	+	–	Maracujá-de-estalo	Lia	Feb-Jan	N	Nascimento *et al.* (2014)
Polygonaceae								
Antigonon leptopus Hook. & Arn.	Reis, H.S. 127	–	+	Amor-agarradinho	Lia	Oct-Dec	N/P	Silva *et al.* (2014a)
Rosaceae								
Rosa alba L.	Reis, H.S. 129	–	+	Rosa-branca	Sub	Oct	P	Modro *et al.* (2011)
Rubiaceae								
Borreria verticillata (L.) G.Mey.	Reis, H.S. 92	+	+	Vassourinha-de-botão	Her	Dec-Jan-July	N	Santos RF *et al.* (2006)
Genipa americana L.	Reis, H.S. 147	–	+	Jenipapeiro	Tree	Dec	N	Nascimento *et al.* (2014)
Hexasepalum radula (Willd.) Delprete & J.H.Kirkbr.	Reis, H.S. 85	–	+	Erva-de-lagarto	Her	July-Nov	N	Santos RF *et al.* (2006)
Richardia grandiflora (Cham. & Schltdl.) Steud.	Reis, H.S. 64	+	–	Quebra-tigela-de-brejo	Her	Jan-May	N/P	Santos RF *et al.* (2006)
Rutaceae								
Murraya paniculata (L.) Jack	Reis, H.S. 153	–	+	Murta-dos-jardins	Tree	Jan	N	Silva *et al.* (2014a)
Solanaceae								
Solanum paniculatum L.	Reis, H.S. 29	+	–	Jurubeba	Shru	Jan-Oct-Dec	P	Maia-Silva *et al.* (2012)
S. stipulaceum Willd. ex Roem. & Schult.	Reis, H.S. 40	+	–	Jurubeba-braba	Shru	Jan-Dec	P	Aguiar *et al.* (2003)
Talinaceae								
Talinum fruticosum (L.) Juss.	Reis, H.S. 20	+	–	Caruru	Her	Jan-Dec	N/P	Maia-Silva *et al.* (2012)
Verbenaceae								
Lantana camara L.	Reis, H.S. 90	–	+	Camará	Shru	July-Oct	N	Maia-Silva *et al.* (2012)
L. fucata Lindl.	Reis, H.S. 118	–	+	Camará	Shru	Sep	N/P	Moreira & Bragança (2011)
Lippia alba (Mill.) N.E.Br. ex Britton & P.Wilson	Reis, H.S. 124	–	+	Cidreira-do-campo	Shru	Sep	N/P	Salis *et al.* (2017)

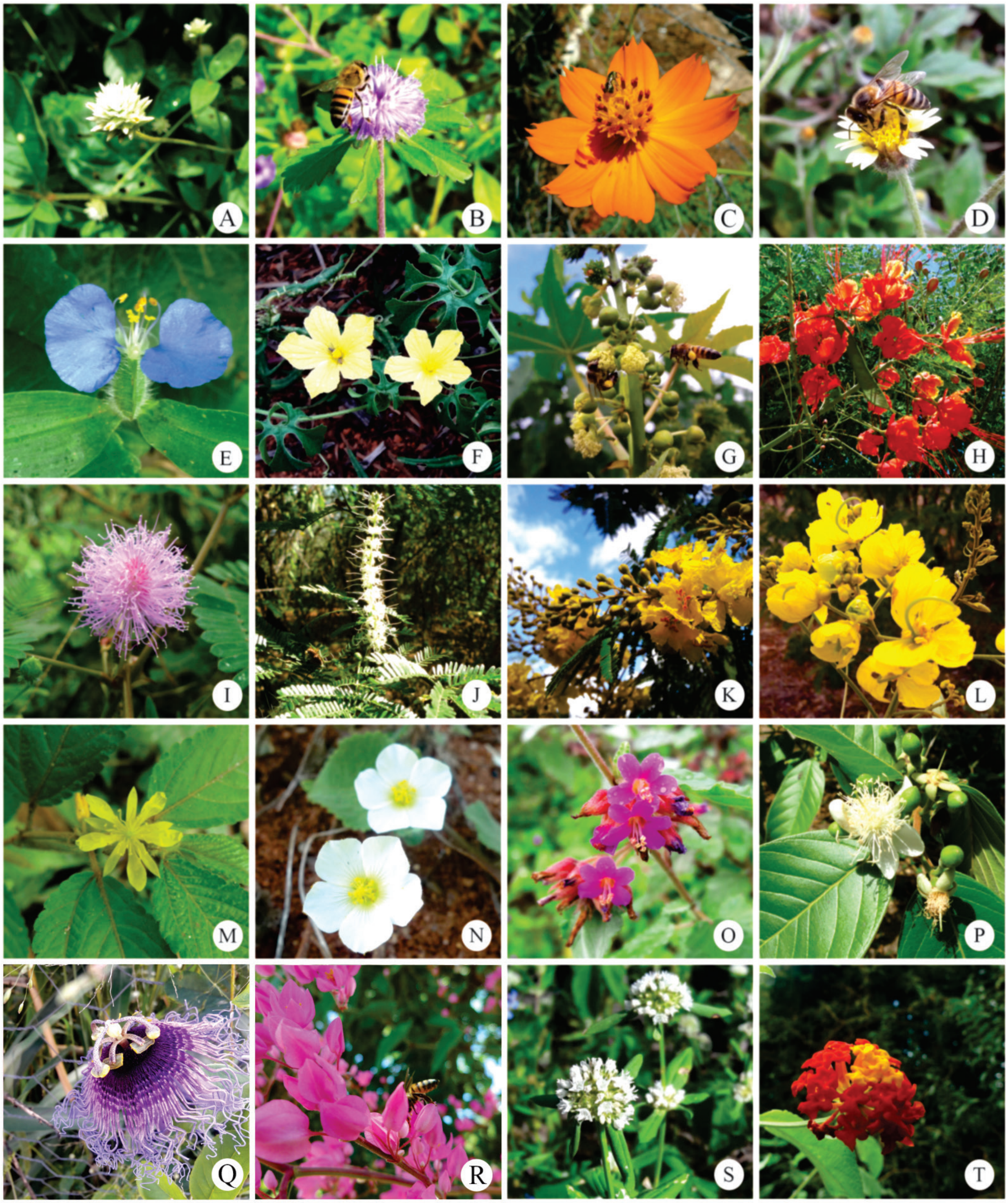

Figure 2. Some bee plant species visited by *Apis mellifera* L. in the municipalities of Antônio Gonçalves and Campo Formoso, State of Bahia, Brazil. Amaranthaceae: **A** – *Alternanthera brasiliana* (L.) Kuntze. Asteraceae: **B** – *Centratherum punctatum* Cass.; **C** – *Cosmos sulphureus* Cav.; **D** – *Tridax procumbens* L. Commelinaceae: **E** – *Commelina erecta* L. Cucurbitaceae: **F** – *Momordica charantia* L. Euphorbiaceae: **G** – *Ricinus communis* L. Fabaceae: **H** - *Caesalpinia pulcherrima* (L.) Sw. **I** – *Mimosa pudica* L.; **J** – *Mimosa tenuiflora* (Willd.) Poir.; **K** – *Peltophorum dubium* (Spreng.) Taub.; **L** – *Senna spectabilis* (DC.) H.S.Irwin & Barneby. Malvaceae: **M** – *Corchorus hirtus* L.; **N** – *Herissantia crispa* (L.) Brizicky.; **O** - *Melochia tomentosa* L. Myrtaceae: **P** – *Psidium guajava* L. Passifloraceae: **Q** – *Passiflora cincinnata* Mast. Polygonaceae: **R** – *Antigonon leptopus* Hook. & Arn. Rubiaceae: **S** – *Borreria verticillata* (L.) G.Mey. Verbenaceae: **T** – *Lantana camara* L.

(Fig. 3). In this municipality, the flowering peak of bee plant species was between September and November (2019) (Fig. 3), characterized by reduced rainfall.

Most bee plant species visited by *A. mellifera* showed flowers arranged in inflorescences (83.52 %) with petals of different colours, such as white (35.29 %) in *Borreria verticillata* (Fig. 2S) and yellow (25.88 %) in *Senna spectabilis* (DC.) H.S.Irwin & Barneby (Fig. 2L). Species with actinomorphic flowers were predominant (70.58 %) (*B. verticillata* – Fig. 2S) regarding zygomorphic flowers (29.42 %) (*Commelina erecta* L. – Fig. 2E). Some species also showed strong odours, and others more sweet and soft odours.

Regarding the vegetation layers, the study area showed mostly herbs (32 spp.), followed by trees (20 spp.), shrubs (16 spp.), subshrubs (nine spp.), and lianas (eight spp.) (Table 2, Fig. 4).

Most herbs recorded were highlighted by offering nectar (37.5 %) as the primary flora resource offered to bees, being also the floral resource most foraged by bees in the study area (Fig. 4). Nectar-offering species represented 40 % of the total bee flora, followed by nectar-pollen-offering (32.94 %) and pollen-offering (25.88 %) species. *Stigmaphyllon paralias* A.Juss. (Malpighiaceae) was the single species to offer oil as the primary floral resource. Representatives from Fabaceae and Rubiaceae were among the most foraged bee plant species offering nectar and pollen. In species from Melastomataceae and Solanaceae, pollen was the sole floral resource offered, as well as in fours species of *Senna* (Fabaceae; *S. aversiflora*, *S. occidentalis* (L.) Link, *S. rugosa* (G.Don) H.S.Irwin & Barneby, and *S. spectabilis*).

The analysis of floristic similarity showed the formation of two distinct groups in the dendrogram, groups A and B (Fig. 5), which shared a considerable number of beekeeping plant species. In group A, the municipalities of Antônio

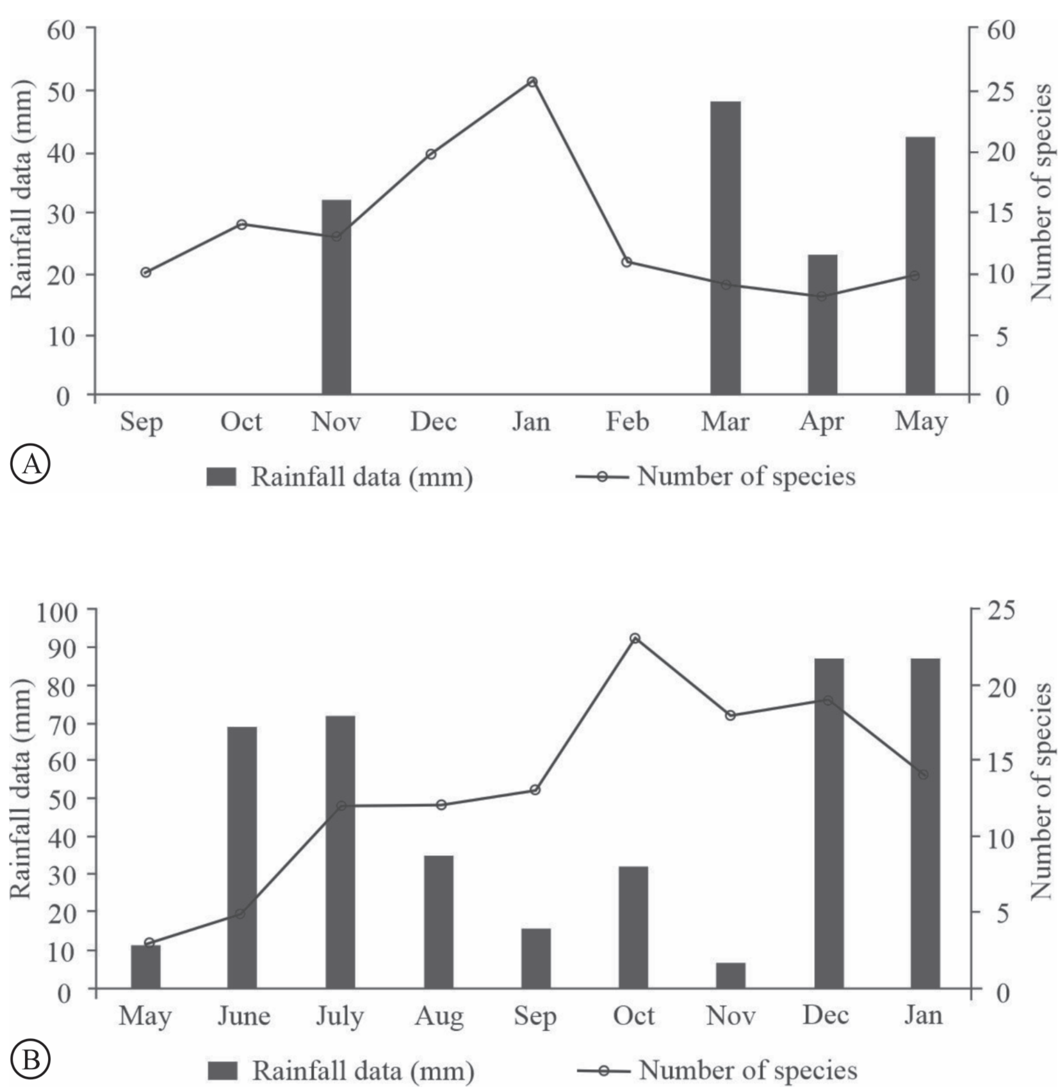

Figure 3. Number of bee plant species monthly visited by *Apis mellifera* in the municipality: **A** - Antônio Gonçalves (September 2016 to May 2017); **B** - Campo Formoso (May 2019 to January 2020) (INMET, 2020).

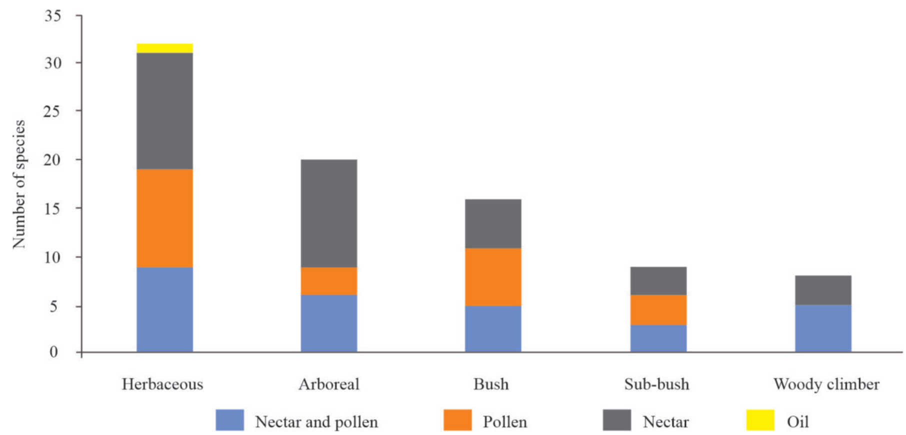

Figure 4. Distribution relation of floral resources by number of species according to habit type.

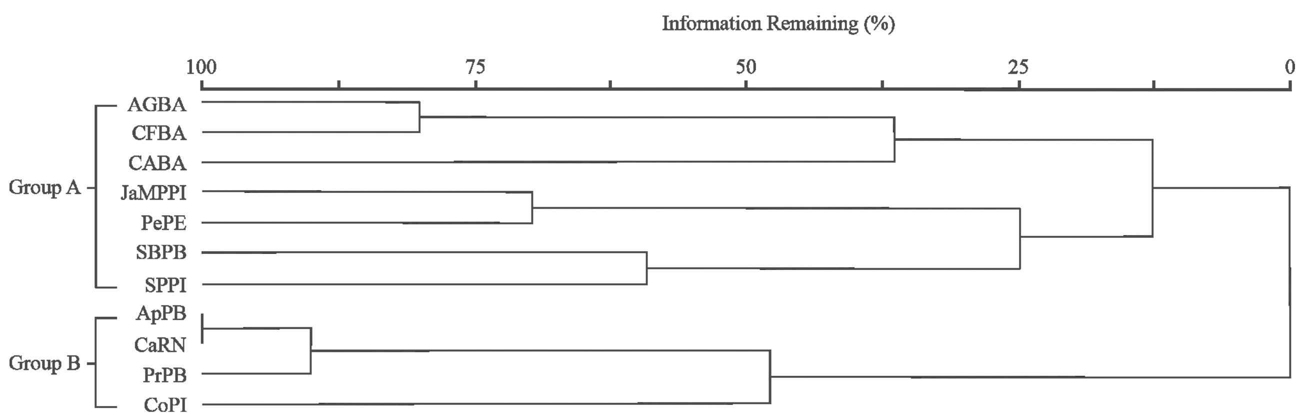

Figure 5. Floristic similarity dendrogram between the municipalities of Antônio Gonçalves (AGBA) and Campo Formoso (CFBA), State of Bahia, Brazil and other areas: Cruz das Almas – State of Bahia (CABA), Jaicós and Massapê do Piauí – State of Piauí (JaMPPI), Petrolina – State of Pernambuco (PePE), São José do Bonfim – State of Paraíba (SBPB), São João do Piauí – State of Piauí (SPPI), Aparecida – State of Paraíba (ApPB), Caraúbas – State of Rio Grande do Norte (CaRN), Prata – State of Paraíba (PrPB), and Cocal – State of Piauí (CoPI).

Gonçalves and Campo Formoso showed high floristic similarity values among them (~84 %). In comparison, the municipality of Cruz das Almas (Bahia) showed only 39.5 % of floristic similarity with the studied areas in municipalities located within the same ecosystem and with high levels of endemism, sharing only seven bee plant species: *Alternanthera brasiliana*, *B. verticillata*, *Centratherum punctatum*, *Syagrus coronata* (Mart.) Becc., *Momordica charantia* L., *Pavonia cancellata*, and *Peltophorum dubium*. In group B, the municipalities of Aparecida and Prata, both in the State of Paraíba, showed high floristic similarity (~90.5 %). However, when compared to the municipalities of Antônio Gonçalves and Campo Formoso, similarity levels were low.

Pollen morphology of bee plant species

From the total bee plant species recorded in the studied areas (Table 2), 20 spp. (23.52 %) distributed into 18 genera and 11 botanical families had their pollen grains analyzed and described (Tables 3, 4, 5): *A. brasiliana*, *Anacardium occidentale*, *Anadenanthera colubrina*, *B. verticillata*, *C. punctatum*, *Croton jacobinensis*, *Heliotropium indicum* L., *Mangifera indica*, *Melochia tomentosa* (short-styled and long-styled flowers), *Mimosa pudica* L., *M. tenuiflora*, *M. charantia*, *P. cancellata*, *P. dubium*, *Psidium guajava*, *Richardia grandiflora* (Cham. & Schltdl.) Steud., *Sida cordifolia* L., *S. galheirensis*, *S. coronata*, and *Waltheria indica* L.

All species palynologically analyzed here showed great morphological diversity regarding dispersal units, polarity, size, shape, aperture and, mostly, exine ornamentation (Table 3). Most species showed pollen grains dispersed into monads (85.71 %), such as *B. verticillata*, *C. jacobinensis*, *M. indica*, *M. charantia*, and *R. grandiflora* (Table 3). Only *A. colubrina* showed pollen grains dispersed in polyads, while only *M. pudica* and *M. tenuiflora* showed tetrads.

Regarding size, most pollen grains observed were medium-sized (42.85 %), followed by large-sized (28.57 %), very large-sized in *P. cancellata*, very small-sized in *M. pudica*), and small-sized in *A. brasiliana*, *B. verticillata*, and *P. guajava* (Tables 4, 5). Shapes varied from subprolate, prolate to prolate spheroidal in 42.85 % of the analyzed species. Other shapes were also recognised as suboblate (*B. verticillata*), oblate (*P. guajava*), and oblate spheroidal (*W. indica* and *R. grandiflora*).

Table 3. Morphological characters of pollen grains from the most representative bee plant species recorded at least in three municipalities from the floristic similarity analysis. Dispersal unit (DU); monad (Mo); tetrad (T); Polyad (P); small (Sm); very small (VS); medium (M); large (L); very large (VL); polarity (Po); apolar (A); isopolar (I); heteropolar (H); spheroidal (Sph); elliptical (El); circular (C); subcircular (Sc); triangular (Tr); subtriangular (St); quadrangular (Q); subquadrangular (Sq); Shape (Sh); prolate (Pr); subprolate (Sp); prolate spheroidal (PS); oblate (O); oblate spheroidal (OS); suboblate (So); sexine (S) and nexine (N).

Family/Species	Morphological characters							
	DU	Size	Po	Amb	Sh	Aperture	Exine ornamentation	S/N
Amaranthaceae								
Alternanthera brasiliana (L.) Kuntze	Mo	Sm	A	Sph	–	12-porate	Metareticulate homobrocate	S<N
Anacardiaceae								
Anacardium occidentale L.	Mo	M	I	Sc	Sp	3-colporate	Striate-microreticulate	S>N
Mangifera indica L.	Mo	M	I	St	Sp	3-colporate	Striate-microreticulate	S>N
Arecaceae								
Syagrus coronata (Mart.) Becc.	Mo	M	H	–	Pr	Sulcate	Psilate	S=N
Asteraceae								
Centratherum punctatum Cass.	Mo	M	I	Sc	PS	3-colporate	Echinolophate	S=N
Boraginaceae								
Heliotropium indicum L.	Mo	M	I	St	Pr	3-colporate	Psilate	S=N
Cucurbitaceae								
Momordica charantia L.	Mo	L	I	Sc	PS	3-colporate	Reticulate heterobrocate	S>N
Euphorbiaceae								
Croton jacobinensis Baill.	Mo	L	A	Sph	–	Inaperturate	Croton pattern	S=N
Fabaceae								
Anadenanthera colubrina (Vell.) Brenan	P	M	–	C	–	Porate	Areolate	S<N
Mimosa pudica L.	T	VS	–	–	–	Porate	Areolate	S=N
Mimosa tenuiflora (Willd.) Poir.	T	Sm	–	El	–	3(-4)-porate	Areolate	S<N
Peltophorum dubium (Spreng.) Taub.	Mo	L	I	C	Sp	3-colporate	Reticulate heterobrocate	S>N
Malvaceae								
Melochia tomentosa L. (brevistila)	Mo	M	I	St/Sq	PS	3(-4)-colporate	Microechinate	S<N
Melochia tomentosa L. (longistila)	Mo	M	I	Sc	PS	3-colporate	Suprareticulate	S=N
Pavonia cancellata (L.) Cav.	Mo	VL	A	Sph	–	Porate	Echinate- granulate	S>N
Sida cordifolia L.	Mo	L	A	Sph	–	Porate	Echinate- granulate	S<N
Sida galheirensis Ulbr.	Mo	L	A	Sph	–	Porate	Echinate- granulate	S<N
Waltheria indica L.	Mo	M	I	C	OS	5(-4)-colporate	Microreticulate heterobrocate	S>N
Myrtaceae								
Psidium guajava L.	Mo	Sm	I	Tr/Q	O	3(-4)-colporate	Microreticulate	S=N
Rubiaceae								
Borreria verticillata (L.) G.Mey.	Mo	Sm	I	C	So	5(-6)-colporate	Microreticulate heterobrocate	S>N
Richardia grandiflora (Cham. & Schtdl.) Steud.	Mo	L	I	C	OS	16(-17)-18-colporate	(micro)echinate granulate	S>N

Table 4. Morphometric characters from isopolar pollen grains from the most representative bee plant species recorded at least in three municipalities from the floristic similarity analysis. Pollen grain diameters (µm): polar axis (PA); equatorial diameter (ED); variation range (R); sexine (S); nexine (N).

Family/ Species	PA		ED		Exine		P/E
	$\bar{x}\pm S\bar{x}$	R	$\bar{x}\pm S\bar{x}$	R	S	N	
Anacardiaceae							
Anacardium occidentale L.	43.28±6.58	30-53	33.04±3.95	25-42	2.40	1.00	1.30
Mangifera indica L.	29.32±3.41	21-36	25.20±2.46	20-29	1.14	1.00	1.17
Arecaceae							
Syagrus coronata (Mart.) Becc.	36.72±1.67	35-40	18.36±1.97	15-22	1.00	1.00	2.00
Asteraceae							
Centratherum punctatum Cass.	28.28±1.81	25-31	27.72±1.72	25-31	1.00	1.00	1.02
Boraginaceae							
Heliotropium indicum L.	40.36±1.52	37-43	29.04±1.27	26-31	1.00	1.00	1.38
Cucurbitaceae							
Momordica charantia L.	62.08±6.55	50-71	58.24±3.85	51-66	2.70	1.00	1.06
Fabaceae							
Peltophorum dubium (Spreng.) Taub.	51.70±2.80	47-58	44.30±3.33	40-50	4.40	1.60	1.16
Malvaceae							
Melochia tomentosa L. (brevistila)	47.80±2.17	43-50	46.92±2.61	42-54	0.97	1.12	1.01
Melochia tomentosa L. (longistila)	46.20±0.90	39-52	42.60±1.10	35-55	1.00	1.00	1.08
Waltheria indica L.	42.16±3.64	38-51	43.40±3.59	38-53	1.20	1.00	0.97
Myrtaceae							
Psidium guajava L.	15.56±1.75	11-18	24.28±2.01	20-28	0.50	0.50	0.64
Rubiaceae							
Borreria verticillata (L.) G.Mey.	18.92±1.41	16-22	21.80±1.73	18-25	0.55	0.50	0.86
Richardia grandiflora (Cham. & Schtdl.) Steud.	80.30±2.30	65-90	80.80±2.90	70-92	1.00	0.95	1.00

Table 5. Morphometric characters from apolar pollen grains, tetrads and polyads from the most representative bee plant species recorded at least in three municipalities from the floristic similarity analysis. Pollen grain diameters (µm): larger diameter (LD); smaller diameter (SD); variation range (R); sexine (S); nexine (N).

Family/Species	Apolar pollen grain, tetrad, polyad				Exine	
	LD		SD			
	$\bar{x}\pm S\bar{x}$	R	$\bar{x}\pm S\bar{x}$	R	S	N
Amaranthaceae						
Alternanthera brasiliana (L.) Kuntze	18.72±1.48	15–21	–	–	0.80	0.95
Euphorbiaceae						
Croton jacobinensis Baill.	91.88±5.30	80-100	–	–	1.00	1.00
Fabaceae						
Anadenanthera colubrina (Vell.) Brenan	36.20±2.46	32-42	33.32±1.88	29-36	0.66	0.90
Mimosa pudica L.	9.24±0.52	10-8	8.76±0.52	8-10	0.97	
Mimosa tenuiflora (Willd.) Poir.	20.56±1.26	18-23	10.04±1.42	8-14	0.50	0.65
Malvaceae						
Pavonia cancellata (L.) Cav.	127.4±2.38	45-55	–	–	1.80	1.00
Sida cordifolia L.	80.16±3.23	75-85	–	–	0.90	0.95
Sida galheirensis Ulbr.	80.20±4.01	70-88	–	–	1.00	1.83

Pollen grains polarity varied from isopolar in most species (57.14 %) to apolar in species of Amaranthaceae (*A. brasiliana*), Euphorbiaceae (*C. jacobinensis*) and Malvaceae (*P. cancellata*, *S. cordifolia*, and *S. galheirensis*), and heteropolar in species of Arecaceae (*S. coronata*). The amb circular was observed in most of the analyzed species (50 %), subcircular in *A. occidentale*, *C. punctatum, M. tomentosa* (long-styled), *M. charantia*, triangular to quadrangular in *P. guajava*, subtriangular in *M. indica* and *H. indicum*, and subquadrangular in *M. tomentosa* (short-styled) (Figs. 6, 7).

The aperture types in the studied pollen grains were simple, with pores in *A. brasiliana* (12-pantoporate) and *M. tenuiflora* [3(-4)-porate] and with colpi in *R. grandiflora* [16(-17)-18-zonocolpate]. Composed apertures were commonly recorded with 3-colporate in 42.85 % of species, such as in *Anacardium occidentale*, *Centratherum punctatum*, and *Peltophorum dubium*; 3(-4)-colporate in *P. guajava*, 5(-4)-colporate in *W. indica*, and 5(-6)-colporate in *B. verticillata*. Inaperturate (*Croton jacobinensis*) and sulcate (*Syagrus coronata*) pollen grains were also observed.

The exine sculpture of pollen grains was greatly diversified, with 33.33 % of them showing microreticulate to reticulate exine: microreticulate (*P. guajava*, *B. verticillata*, and *W. indica*); suprareticulate (*Melochia tomentosa* – long-styled); metareticulate (*A. brasiliana*), reticulate (*Momordica charantia* and *P. dubium*). Echinate exine and other ornamentation elements were recorded in *R. grandiflora* [(micro)echinate-granulate], *M. tomentosa* (short-styled morph) (microechinate), *C. punctatum* (echinolophate), *P. cancellata*, *S. cordifolia*, and *S. galheirensis* (echinate-granulate). The *Croton*-type ornamentation was observed in Euphorbiaceae (*C. jacobinensis*); striate-microreticulate in Anacardiaceae (*Mangifera indica* and *A. occidentale*), areolate in species of Fabaceae (*Anadenanthera colubrina*, *M. pudica*, and *M. tenuiflora*), and psilate in Arecaceae (*S. coronata*) and Boraginaceae (*Heliotropium indicum*).

Discussion

Diversity of the bee flora

The diversity of bee plant species in this study shows the importance of these species for beekeeping and honey production of *Apis mellifera* hives in the region, being important for bee foraging for pollen, nectar, resin or oils. Santos *et al.* (2006a) also showed the great diversity of beekeeping plant species occurring in this region of the Bahian semiarid, which are frequently foraged by *A. mellifera* on a daily basis.

Species from Fabaceae, Malvaceae, Asteraceae, Euphorbiaceae, and Rubiaceae comprise 55.29 % of the total species visited by *Apis mellifera* in the study areas. Several floristic surveys in the Caatinga domain have shown that these families represent most of the plant diversity from Northeast Brazil (Araújo *et al.* 2010; Bessa & Medeiros 2011; Lima *et al.* 2012; Sanquetta *et al.* 2014; Bulhões *et al.* 2015; Luna *et al.* 2015; Sabino *et al.* 2016). Fabaceae and Malvaceae are highlighted due to the great number of species of beekeeping importance due to offering nectar/pollen to bees in the studies of Santos *et al.* (2006a) and Moraes *et al.* (2020).

When comparing the diversity of species recorded by botanical families in this study with other floristic surveys in the State of Bahia (Nascimento *et al.* 2014; Carvalho & Marchini 1999; Viana *et al.* 2006) or with other studies regarding the interaction between plants and bees (Aguiar 2003; Milet-Pinheiro & Schlindwein 2008), one can note that Fabaceae, Asteraceae, Malvaceae, Rubiaceae and Euphorbiaceae are among the most representative families with beekeeping importance. In areas of Caatinga, species of these families are regarded as excellent suppliers of trophic resources to bees (Nascimento *et al.* 2014; Costa *et al.* 2015; Machado & Lopes 2006; Santos *et al.* 2006b). According to Salis *et al.* (2015; 2017), some plant species from Fabaceae are regarded as having beekeeping potential due to offering nectar and pollen for extensive flowering periods.

The analyses of honey samples from the municipalities of Antônio Gonçalves and Campo Formoso (Reis *et al.* 2021), recorded a variety of pollen types corroborating the great diversity of species, genera and families of the bee flora from this region. When compared to our results, Fabaceae and Malvaceae are highlighted due to the diversity of pollen grains recorded, mostly in *Mimosa* (Fabaceae) and *Herissantia* (Malvaceae). For Oliveira & Santos (2014), these types of pollen grains recorded in honey, coupled with their morphological characters, might be related to the several species from their genera. Thus, pollen types related to *Mimosa* recorded by Reis *et al.* (2021) might represent the species *Mimosa candollei*, *M. tenuiflora*, and *M. pudica* recorded in the study areas. In contrast, the *Herissantia* pollen type might be related to the species *H. crispa* and *H. tiubae*.

Some species that flowered during the dry season in this study possibly have alternative strategies for pollinator attraction, as well as morphological and physiological adaptations, making them more resilient during the dry season (Mantovani & Martins 1988; Barbosa *et al.* 2003). According to Silva *et al.* (2008), during the dry season, there are several plant species flowering in the Caatinga domain, such as *M. tenuiflora*, which blooms during the first dry months of the year, followed by *Anadenanthera colubrina*.

The results presented here for blooming plant species important for beekeeping during the dry season corroborate data from the specialized literature from the Caatinga domain, such as Carvalho & Marchini (1999), Aguiar (2003), Costa *et al.* (2018), Silva-Filho *et al.* (2010), among others. For Silva *et al.* (2015), *M. tenuiflora* is regarded as a species of important beekeeping activities in the Caatinga, recommending its conservation and propagation in places with apiaries. Carvalho & Marchini (1999) and Vidal *et al.* (2008) highlighted that *Melochia tomentosa* and *Antigonon leptopus* bloom all year long, possibly being important sources of nectar and/or pollen for bees when the Caatinga vegetation shows little resources to them.

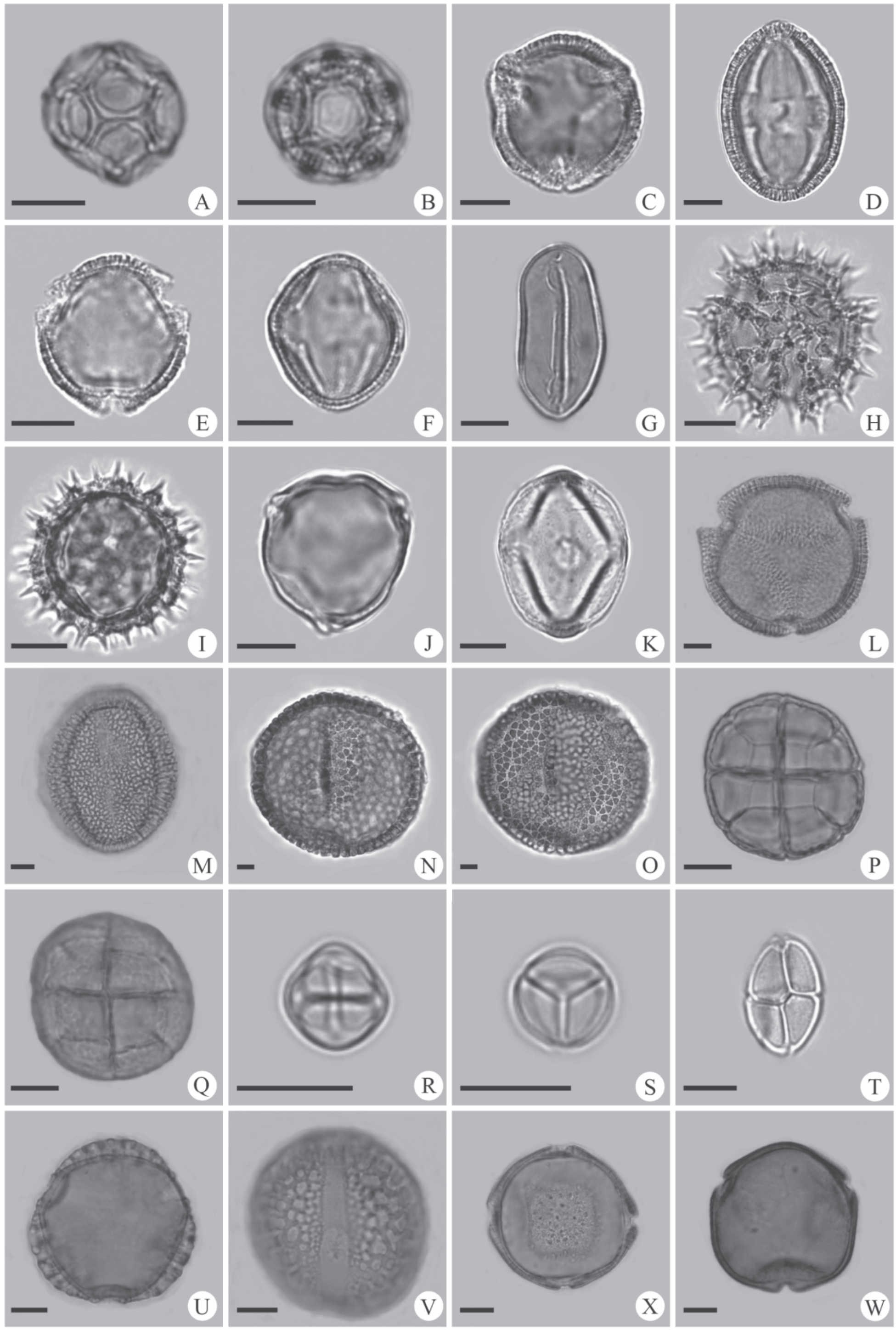

Figure 6. Pollen grains from the most representative bee plant species in the municipalities of Antônio Gonçalves and Campo Formoso, State of Bahia, Brazil. Amaranthaceae: *Alternanthera brasiliana* (L.) Kuntze (**A** – surface, aperture; **B** – surface). Anacardiaceae: *Anacardium occidentale* L. (**C** – polar view, optical cut; **D** – equatorial view, optical cut), *Mangifera indica* L. (**E** – polar view, optical cut; **F** – equatorial view, optical cut). Arecaceae: *Syagrus coronata* (Mart.) Becc. (**G** – surface, aperture). Asteraceae: *Centratherum punctatum* Cass. (**H** – polar view, surface; **I** – equatorial view, optical cut). Boraginaceae: *Heliotropium indicum* L. (**J** – polar view, optical cut; **K** – equatorial view, surface). Cucurbitaceae: *Momordica charantia* L. (**L** – polar view, optical cut; **M** – equatorial view, surface). Euphorbiaceae: *Croton jacobinensis* Baill. (**N** – optical cut; **O** – surface). Fabaceae: *Anadenanthera colubrina* (Vell.) Brenan (**P** – frontal view, optical cut; **Q** – frontal view, surface), *Mimosa pudica* L. (**R** - frontal view, decussate tetrad; **S** – frontal view, tetrahedral tetrad), *Mimosa tenuiflora* (Willd.) Poir. (**T** – frontal view, surface), *Peltophorum dubium* (Spreng.) Taub. (**U** – polar view, optical cut; V – equatorial view, surface, aperture). Malvaceae: *Melochia tomentosa* L. (short-styled) (**X** – polar view, optical cut [four apertures]; **W** – polar view, optical cut [three apertures]). (Scale = 10 μm)

The diversity of floral attributes (color, symmetry, attraction unit and scent) presented by the different species that provide resources for the bees, as described in the present study, aid determine their beekeeping importance, contributing to attracting floral visitors, especially potential pollinators (Covre & Guerra 2016; Brito *et al.* 2017; Melo *et al.* 2018; Silva *et al.* 2020). According to Araújo *et al.* (2009) and Covre & Guerra (2016), flowers arranged in inflorescences, aside from concentrating resources, also increase flower visibility and attract more pollinators.

The large representation of mainly nectariferous species reported in the present study corroborates the results obtained by Santos *et al.* (2006b) in the Caatinga, as well as other studies in other vegetation types, such as Viana *et al.* (2006) for restinga formations and Lopes *et al.* (2016) for the Cerrado. For the latter studies, there might not be

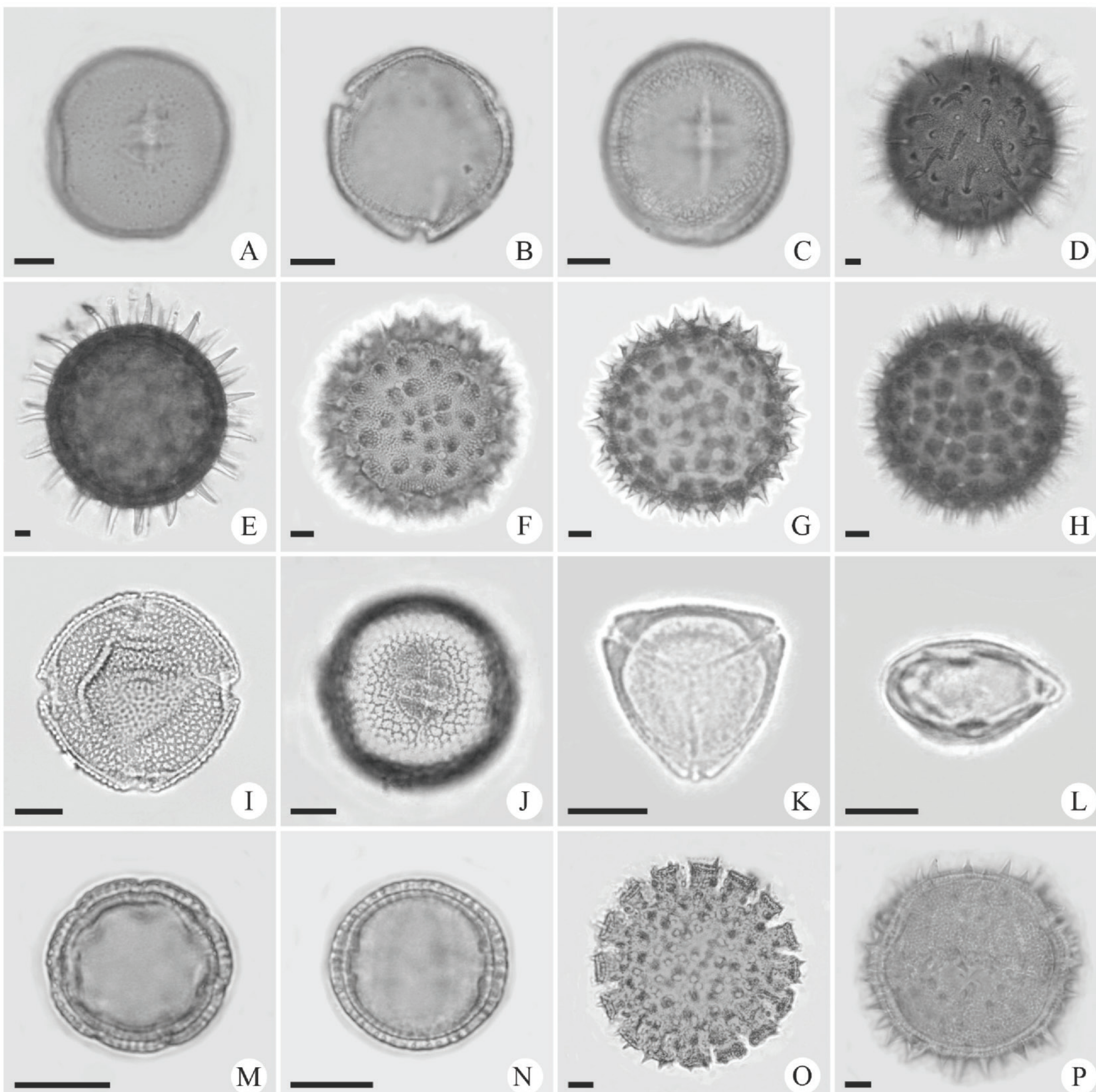

Figure 7. Pollen grains from the most representative bee plant species in the municipalities of Antônio Gonçalves and Campo Formoso, State of Bahia, Brazil. Malvaceae: *Melochia tomentosa* L. (short-styled) (**A** – equatorial view, aperture), *Melochia tomentosa* L. (long-styled) (**B** – polar view, optical cut; **C** – equatorial view, aperture), *Pavonia cancellata* (L.) Cav. (**D** – frontal view, surface; **E** – frontal view, optical cut), *Sida cordifolia* L. (**F** – frontal view, surface; **G** – frontal view, optical cut), *Sida galheirensis* Ulbr. (**H** – frontal view, surface), *Waltheria indica* L. (**I** – polar view, optical cut; **J** – equatorial view, surface). Myrtaceae: *Psidium guajava* L. (**K** – polar view, surface; **L** – equatorial view, surface, aperture). Rubiaceae: *Borreria verticillata* (L.) G.Mey. (**M** – polar view, optical cut; **N** – equatorial view, optical cut), *Richardia grandiflora* (Cham. & Schltdl.) Steud. (**O** – polar view, optical cut; **P** – equatorial view, surface). (Scale = 10 μm)

a pattern of floral resources offered for bees in regions with different vegetation types.

Regarding the species of *Senna* reported by us, Moura *et al.* (2018) highlight that due to the genus' poricidal anthers, pollen is their only floral resource. The sharing of bee species between certain areas seems to indicate the existence of a foraging pattern between bee species, which includes *Apis mellifera*, that despite foraging a wide range of plants species, shows a clear preference for certain species in each area (Aguiar *et al.* 2002; Pott & Pott 1986). This can be attributed to the occurrence of distinct and predominant vegetation types in each area.

Pollen morphology of bee plant species

In the present study, we have provided the pollen morphology of 20 species with beekeeping importance, arranged into 11 plant families. According to Lima *et al.* (2006) and Moreti *et al.* (2007), understanding the pollen morphology of bee plant species is essential to enable a reliable palynological analysis, characterization and identification of the palynological content of hive products since they allow the identification of their floral and geographic origin.

According to Marques-Souza *et al.* (2002), Koch *et al.* (2017), Rasoloarijao *et al.* (2019) and Konzmann *et al.* (2020), some morphological characteristics of the pollen grains can highlight the plant-pollinator correlation, favouring the pollination process by helping adhered grains to the bee body and its posterior transfer to the stigmatic surface. Lunau *et al.* (2015) and Konzmann *et al.* (2019) highlight that some exine ornamentation elements can affect their collection and storage by bees.

The descriptions provided by us in the present study, associated with the pollen dispersal of certain taxa, are in agreement with several previous studies (Melhem *et al.* 2003; Lima *et al.* 2006; Moreti *et al.* 2007; Corrêa *et al.* 2010; Silva *et al.* 2016a; Lorente *et al.* 2017). When describing the pollen morphology of melliferous used by *Apis mellifera unicolor*, Rasoloarijao *et al.* (2019) verified that 97 % of the studied species had pollen grains dispersed as monads. This data is also supported by the present study. Only two genera, *Anadenanthera* and *Mimosa*, had pollen not dispersed as monads, being dispersed as poliads and tetrads, respectively. *Mimosa*-type pollen is commonly observed in apiculture products as the dominant or codominant pollen type (Oliveira *et al.* 2010; Nascimento *et al.* 2015; Santos *et al.* 2020).

Medium-size pollen grains were the predominant size among the studied species (42.85 %), followed by large-size grains (28.57 %), with the smallest grains being observed for the tetrads of *Mimosa pudica* and the largest ones observed for *Pavonia cancellata* (Malvaceae). These results corroborate data found in other studies on pollen morphology of the taxa studied here (Lima *et al.* 2008; Buril *et al.* 2010; Corrêa *et al.* 2012; Matos *et al.* 2014; Pereira *et al.* 2014; Nascimento *et al.* 2021).

According to Culley *et al.* (2002), relatively small and light-weight pollen grains are common in wind-dispersed species. Large-sized pollen grains have a higher nutritional value for bees due to their increased content. Furthermore, their size does not interfere with their collection by bees but does make them more visible to these animals (Konzmann *et al.* 2019; Rasoloarijao *et al.* 2019). Marques-Souza *et al.* (2002), while studying biochemical and morphological aspects of the pollen grains collected by five species of meliponid bees, observed that these bees collect grains of different sizes. They were able to confirm that pollen grain size did not play an important role for the bees when selecting which flowers to visit and pollen to collect.

Regarding pollen grain polarity, most species analyzed by us presented isopolar pollen grains, with a single record of apolar and heteropolar grains in *Syagurus coronata*. Grains with amb (sub)circular and prolate shape, including these categories' subtypes, were predominant amongst the studied taxa. The descriptions presented by us are in agreement with Gasparino *et al.* (2014) for palynological flora of the Parque Estadual das Fontes do Ipiranga, State of São Paulo, Silva *et al.* (2016) for the Caatinga vegetation in Canudos, State of Bahia, and Nascimento *et al.* (2021) for the bee plant species in the Recôncavo Baiano region, Bahia.

Pollen grain shape does not seem to influence pollination, as well as bee attraction and foraging (Marques-Souza *et al.* 2002; Rasoloarijao *et al.* 2019). Saba *et al.* (2004) described the pollen morphology for species of *Melochia* (Malvaceae), including *M. tomentosa*. They observed similar characteristics regarding the medium (short- and long-style morphs) to the large size of the grains (long-style morph) and the oblate-spheroidal (short- and long-style morphs) to spheroidal shape (long-style morph). Saba *et al.* (2004) and Silveira-Júnior *et al.* (2017) describe the pollen grains for the studied species of *Waltheria* (Malvaceae). However, their descriptions for homostylic *W. indica* differ from the one presented by us, especially regarding pollen grain shape and size. Silveira-Júnior *et al.* (2012) observed that pollen grains of *Richardia grandiflora* were large-sized and suboblate, differing from our present observations. For Myrtaceae, our observations for *Psidium guajava* agree with the descriptions provided by Corrêa *et al.* (2018) in their small size and oblate shape.

The colporate aperture type was the most common amongst the species analyzed in the present study. We also less frequently observed pollen grains with simple apertures (i.e., pores, colpi and sulci), as well as inaperturate grains. Aperture diversity in pollen grains is widely observed in studies that focus on the pollen morphology of different plant families, especially for those with foraging and beekeeping potential (Lima *et al.* 2006; Moreti *et al.* 2007; Dec & Mouga 2014; Matos *et al.* 2014; Nascimento & Carvalho 2019; Rasoloarijao *et al.* 2019).

Moreti *et al.* (2007) describe the pollen grains of the main species of Fabaceae with beekeeping potential. Most of the studied grains (95 %) were colporate, while only 2.5 % were colpate. Dec & Mouga (2014) describe colporate pollen grains for some bee species of Euphorbiaceae. Nonetheless, some species did not have their aperture type described, possibly due to being inaperturate, a character commonly observed in some members of this family (Souza *et al.* 2016). For members of Myrtaceae, Nascimento & Carvalho (2019) report that species in this family are visited by bees and have colporate pollen grains. In the present study, most species of Myrtaceae (52.38 %) presented colporate grains.

Our present observations on exine ornamentation are in agreement with previous studies for the taxa studied by us (Melhem *et al.* 2003; Saba & Santos 2003; Saba *et al.* 2004; Melo *et al.* 2006; Lima *et al.* 2008; Buril *et al.* 2010; Cassino *et al.* 2016; Silva *et al.* 2016a; Souza *et al.* 2016; Lorente *et al.* 2017). Some inconsistencies between previous studies are worth mentioning, such as the exine ornamentation of *Mimosa tenuiflora*, described as scabrate by Buril *et al.* (2010) and as psilate by Lima *et al.* (2006).

Mora *et al.* (2013) describe the pollen grains of *Mangifera indica* but fail to describe its exine ornamentation. However, the characters described by us regarding size (medium) and dispersal unit (monad) are in agreement with Mora *et al.* (2013). Pereira *et al.* (2014) and Silva *et al.* (2016a) characterize the pollen grains of *Anacardium occidentale* as having striate-reticulate exine, which disagrees with the striate-microreticulate ornamentation reported by us. Under SEM, Assis *et al.* (2021) described the pollen grains of *A. occidentale* with suprastriato-inframicroreticulate exine and *M. indica* with striato-perforate ornamentation, such perforations were not observed under LM. Matos *et al.* (2014) describe the pollen grains of *Pavonia cancellata* and *Sida linearifolia* A.St.-Hil. as having spinulate-microbaculate and spinulate-pilate exine, respectively. Nonetheless, *P. cancellata*, *S. cordifolia,* and *S. galheirensis* are described in the present study as spinulate-granulate.

Lunau *et al.* (2015), when studying the mechanical protection against pollen grain collection by corbiculate bees, demonstrated that the echinate pollen of *Alcea rosea* L. (Malvaceae) makes it harder for them to be collected and stored in the bees' corbiculae. Nonetheless, this ornamentation type greatly facilitates the grains' adherence to animals, guaranteeing their transport for pollination. Regarding psilate grains, Culley *et al.* (2002) consider them to be typically associated with wind-pollinated species, together with reduced size and reduced number of apertures. Alternatively, heavily ornamented pollen grains with large size and a large number of apertures, especially the elongated ones (i.e., colpi and colpori), are common in insect-pollinated species. Nonetheless, Rasoloarijao *et al.* (2019) highlight that some species with psilate pollen grains offer nectar as a reward, thus being frequently visited by bees.

Conclusion

Our results provided much-needed information on the bee flora of the Caatinga visited by *Apis mellifera* colonies in the State of Bahia. This data aids in the recognition, preservation and multiplication of these organisms, representing a reliable tool for sustainable apicultural techniques, consequently improving the region's apicultural productivity.

The most species-rich plant families were Fabaceae, Malvaceae, Asteraceae, Euphorbiaceae and Anacardiaceae. These were also the families that had their pollen morphology described by us. These species showed a considerable morpho-pollinic variation, especially regarding their aperture type (inaperturate, porate, colpate, sulcate, or mainly colporate), size (predominantly medium-sized) and exine ornamentation (ranging from psilate to echinate). These results contribute greatly to the palynology of bee species, as well as providing data for environmental preservation studies in the Caatinga biome.

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