Richness of gall-inducing insects in the tropical dry forest (caatinga) of Pernambuco

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ABSTRACT. Diversity of gall-inducing insects in the tropical dry forest (caatinga) of Pernambuco. We report on the richness of galling insects in the vegetation of caatinga of Pernambuco state, Brazil. We recorded 64 different types of galls collected primarily from leaves and stems of 48 species of host plants belonging to 17 families and 31 genera. The most common gall morphological types were spheroid and discoid, glabrous, predominantly green and with one chamber. The main gall inducing taxon was the Cecidomyiidae (Diptera). The results of this study contribute to existing knowledge of galling insect and host-plant diversity in caatinga.

KEYWORDS. Cecidomyiidae; host plants; insect galls; insect herbivore; species richness.

RESUMO. Diversidade de insetos indutores de galhas na floresta tropical seca (caatinga) de Pernambuco. Este artigo reporta sobre a riqueza de insetos galhadores na vegetação de caatinga de Pernambuco, Brasil. Foram registrados 64 diferentes tipos de galhas coletadas principalmente em folhas e caules de 48 espécies de plantas hospedeiras pertencentes a 17 famílias e 31 gêneros. Os tipos morfológicos de galhas mais comuns foram esferóide e discóides, glabro, predominantemente verde e com uma câmara. O principal táxon indutor de galhas foi Cecidomyiidae (Diptera). Os resultados deste estudo contribuem para o conhecimento da diversidade de insetos galhadores e planta-hospedeira na caatinga.

PALAVRAS-CHAVE. Cecidomyiidae; galhas entomógenas; insetos herbívoros; plantas hospedeiras; riqueza de espécies.

Gall-inducing insects are very rich in species around the word and the latest global richness estimates the existence between 21,000 to 211,000 species, with an average of 132,930 species (Espírito-Santo & Fernandes 2007). In Brazil, studies addressing the richness of galling insects have been increasing in several ecosystems, such as Atlantic forest (e.g., Fernandes *et al.* 2001; Mendonça 2007; Moreira *et al.* 2007), restinga (Atlantic Coast restingas) (see Oliveira & Maia 2005), wetlands (Pantanal) (Julião *et al.* 2002; Julião *et al.* 2004), Amazon rain forest (Julião *et al.* 2005), but most studies were done in the cerrado (savanna) (e.g., Fernandes *et al.* 1997; Gonçalves-Alvim & Fernandes 2001a, b; Lara *et al.* 2002; Urso-Guimarães *et al.* 2003; Maia & Fernandes 2004; Urso-Guimarães & Scarelli-Santos 2006; Carneiro *et al.* 2009b; Coelho *et al.* 2009). In these ecosystems, the highest species richness of galling insects is concentrated in the rupestrian fields and in the cerrado (savanna) vegetation of southeastern Brazil (Fernandes & Price 1988; Lara & Fernandes 1996). Up to date, the knowledge on the other many tropical vegetations of Brazil is scanty, such as in the seasonally dry tropical forests of northeastern region.

The caatinga, a Brazilian seasonally dry tropical forest, is the fourth largest ecosystem in Brazil and exclusively of Brazil. This tropical dry forest occupies an area of 840,000 km^2, which represented almost 70% of the northeastern region and 10% of the territory in nine Brazilian states (Piauí, Ceará, Rio Grande do Norte, Paraíba, Alagoas, Sergipe, Bahia, Minas Gerais, and Pernambuco) (Castelletti *et al.* 2003). In the state of Pernambuco, the caatinga is the largest ecosystem, occupying an area of approximately 85% of the territory. Less than 1% of the caatinga (only 11 reserves) is protected by conservation areas (Leal *et al.* 2005). The caatinga is a semi-arid vegetation (tropical dry forest), characterized by a deciduous forest, shrub to tree vegetation of extreme drought, which plants undergo severe water shortage during a large portion of the year that lasts from March to October. The rains in the caatinga are irregular throughout the year, the low annual rainfall distribution (500 to 750 mm year^{-1}) occurs only during three to five months, with a water deficit during most months, and the annual average temperature is between 23 and 27ºC (see Prado 2003). For many years, the caatinga was considered a region of poor species diversity, but recent studies have demonstrated that it supports a rich flora with a high degree of endemism of both plants and animals (see Leal *et al.* 2005). Despite its great biological importance, there are exceedingly few ecological studies in the caatinga, especially to insects (J. C. Santos, *pers. comm.*). For the first time, we report on the richness of galling insects in this vegetation in an attempt to broaden our knowledge of galling species diversity in the seasonally tropical dry forests of the Americas.

MATERIAL AND METHODS

Study site. This study was conducted in seven private areas of caatinga (municipalities: Alagoinha, Custódia, Pombos, Bodocó, Serrita, Pesqueira, Salgueiro and Parnamirim), one national park (Parque Nacional Vale do Catimbau – Buíque municipality), and two ecological stations (Universidade Federal Rural de Pernambuco – Serra Talhada municipality and Instituto Agronômico de Pernambuco – Caruaru municipality); all sites located in Pernambuco state, Brazil. These areas were chosen to cover the maximum of the longitudinal variability of the vegetation of the caatinga in the state of Pernambuco and to avoid concentration of sampling in a single area (pseudo-replication), with Pombos the area closest to the coast and Bodocó the farthest area (Fig. 1).

Sampling galling insects richness. The caatinga was investigated for galls over a period of seven months from February to August of 2008, covering part of the rainy season and part of the dry season. This period was chosen because the plants had fully expanded leaves. In each site, galling insect richness were sampled by two people following the adapted methodology of random walking (Julião *et al.* 2002; Fernandes & Negreiros 2006; Coelho *et al.* 2009), where instead of an hour, we spent three hours in each area. To maximize the sampling of richness, a distance of at least 500 meters was established among the sites sampled inside the areas (Fernandes & Price 1988). All plant organs were investigated, and each gall and host plants (up to 3 meters height) found were collected, packed in plastic bags, and then taken to a laboratory for photographic registration and description of the external morphology. Host plants were classified into morphospecies in the field, and later at the species level by specialist before included in the Herbarium UFPE (Universidade Federal de Pernambuco). The classification of species of host plants followed the system proposed by Angiosperm Phylogeny Group II (APG II 2003), and the authors and scientific host plant names were checked in Missouri Botanical Garden website http://mobot.mobot.org/W3T/Search/classicvast.html.

We identified gall morphospecies based upon their external morphology in combination with their host plant species. In general, 95% species of insect induce a gall on a specific tissue of a certain plant species (Carneiro *et al.* 2009a). Therefore, in this article, we consider the gall morphotypes as true species (see also Coelho *et al.* 2009). Galls were characterized as reported by Fernandes & Price (1988): host plant species, number of types of galls by host plant, type of host tissue attacked, shape of galls, color of galls, presence or absence of pubescence, and number of chambers in the gall, occurrence on the galled organ: isolated or grouped/coaslescent. We chose to present only a list with the probable inducers of gall maker because many galls were naturally damaged, or without the presence of the inductor or with inductor parasited. The use of morphospecies to represent the galling species richness is widely accepted in the literature and it has been used in several studies in different ecosystems (e.g., Price *et al.* 1998; Cuevas-Reyes *et al.* 2004; Fernandes & Negreiros 2006; Moreira *et al.* 2007; Coelho *et al.* 2009; see also Carneiro *et al.* 2009a).

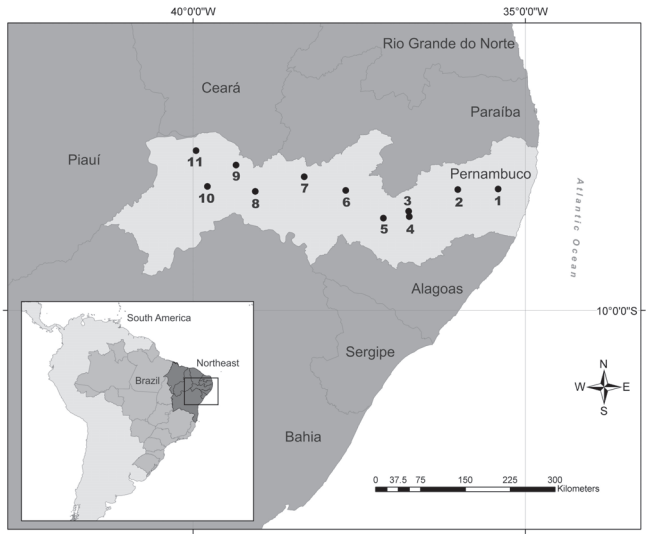

Fig. 1. Location of the studied sites (number) in Pernambuco state (detail), northeast region (light grey) of Brazil (dark grey). 1– Pombos; 2 – Caruaru; 3 – Pesqueira; 4 – Alagoinha; 5 – Buíque; 6 – Custódia; 7 – Serra Talhada; 8 – Salgueiro; 9 – Serrita, 10 – Parnamirim and 11 – Bodocó.

RESULTS

We found 64 morphologically distinct types of insect galls in the caatinga of Pernambuco. These galls were found in 48 species of host plants from 17 families and 31 genera (Table I, Figs. 2–5). The richness of galling insects was greater in the Vale do Catimbau (33 morphotypes) followed by Serra Talhada (11 morphotypes), Parnamirim (nine morphotypes), Caruaru (eight morphotypes), Alagoinhas, Custódia, Pombos and Bodocó each with six morphotypes, Serrita (five morphotypes), Pesqueira (three morphotypes) and Salgueiro with two morphotypes. The majority of galls induced by insects belongs to the family Cecidomyiidae (89%) followed by Coleoptera (5%), Heteroptera (2%) and five percent were undetermined. The host plant families that had a greater number of species of galls were: Fabaceae (23.44%), Euphorbiaceae (14.06%), and Boraginaceae, Malpighiaceae and Myrtaceae with 6.25% each. When we consider the host plant species by family, we found almost the same pattern: Fabaceae (16.67%), Euphorbiaceae (16.67%), and Sapindaceae, Malpighiaceae and Myrtaceae with 8.33% each. The genera with the greatest number of morphospecies of galls were: *Croton* (four species), *Cnidoscolus* (three species), and, *Bauhinia* and *Byrsonima* with two species each. Most galls were induced on the leaves (73.44%), stems (20.31%), and on apical buds (6.25%). The most frequent shape of galls was spheroid (32.81%), followed by discoid (25.00%). Seventy-seven percent of galls were glabrous, 78.13% were predominantly green, while 73.44% did not form clusters.

Table I. Galling insect morphospecies and host plants found in the caatinga of Pernambuco, Brazil. The host plants and description of gall morphotypes are presented below, with the number of galls found on each host plant, plant organ where the gall was induced, area where the gall was induced on the sheet in the form galls, predominant color, presence or no hair, number of chambers (if it is grouped or isolated) and the likely group of the gall inducer. Each gall morphotype of this table is depicted in Figs. 2-5 below.

Host plant family	Host plant species	Galls	Tissue	Side	Shape	Color	Pubescense	Chambers	Likely gall maker	Figures
Anacardiaceae	*Anacardium microcarpum* Ducke	1	Leaf	Both	Globoid	Red	No	Isolated	Cecidomyiidae	2A
Bignoniaceae	*Tabebuia impetiginosa* (Mart. ex DC.) Standl	1	Leaf (petiole)	–	Spheral	Green	No	Isolated	Coleoptera	2B
Boraginaceae	*Cordia leucocephala* Moric.	1	Leaf	Both	Spheral	Green	No	Isolated	Cecidomyiidae	2C
		2	Leaf	Abaxial	Elliptical	Green	No	Isolated	Cecidomyiidae	2D
		3	Stem	–	Elliptical	Green	No	Grouped	Cecidomyiidae	2E
	Tournefortia rubicunda Salzm. ex DC.	1	Fruit	–	Globoid	Green	Yes	Grouped	Cecidomyiidae	2F
Convolvulaceae	Convolvulaceae sp. 1	1	Stem	–	Elliptical	Green	No	Isolated	Cecidomyiidae	2G
		2	Floral bud	–	Globoid	Green	No	–	Cecidomyiidae	2H
		3	Leaf (rib)	Abaxial	Amorphous	Green	No	–	Cecidomyiidae	2I
Erythroxylaceae	*Erythroxylum* cf. *pungens* O.E. Schulz	1	Leaf	Adaxial	Spheral	Green	No	Isolated	Cecidomyiidae	2J
Euphorbiaceae	*Cnidoscolus loefgrenii* (Pax & K. Hoffm.) Pax & K. Hoffm.	1	Leaf	Adaxial	Globoid	Green	No	Isolated	Cecidomyiidae	2K
	Cnidoscolus phyllacanthus (Müll. Arg.) Pax & L. Hoffm.	1	Leaf	Both	Spheral	Green	No	Isolated	Cecidomyiidae	2L
	Cnidoscolus urens (L.) Arthur	1	Leaf	Adaxial	Discoid	Yellow	No	Isolated	Cecidomyiidae	2M
	Croton adamantinus Müll. Arg.	1	Stem	–	Spheral	Brown	No	–	Not identified	2N
	Croton blanchetianus Baill.	1	Leaf	Adaxial	Spheral	Green/Brown	No	Isolated	Cecidomyiidae	2O
		2	Stem	–	Elliptical	Green	No	Grouped	Cecidomyiidae	2P
	Croton echioides Müll. Arg.	1	Leaf	Abaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	2Q
	Croton rhamnifolioides Pax & K. Hoffm.	1	Leaf	Abaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	2R
	Manihot dichotoma Ule	1	Leaf	Adaxial	Cylindrical	Green/Red	No	Isolated	Cecidomyiidae	3A
Fabaceae	*Acacia* sp. Mill.	1	Meristem	–	Globoid	Green	No	Grouped	Cecidomyiidae	3B
	Bauhinia acuruana Moric.	1	Leaf	Adaxial	Globoid	Green	Yes	Isolated	Cecidomyiidae	3C
		2	Leaf	Adaxial	Discoid	Green/Brown	No	Isolated	Cecidomyiidae	3D
		3	Stem	–	Elliptical	Brown	No	Grouped	Cecidomyiidae	3E
	Bauhinia cheilantha (Bong.) Steud.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	3F
		2	Leaf	Adaxial	Spheral	Green	No	Isolated	Cecidomyiidae	3G
		3	Stem	–	Globoid	Brown	No	Grouped	Cecidomyiidae	3H
		4	Leaf	Adaxial	Discoid	Green	No	Isolated	Coleoptera	3I
	Caesalpinia bracteosa Tul.	1	Leaf	Borda	Elliptical	Red	Yes	Isolated	Cecidomyiidae	3J
		2	Stem	–	Globoid	Brown	No	Grouped	Cecidomyiidae	3K
	Fabaceae sp. 1	1	Leaf	Adaxial	Conical	Red	No	Isolated	Cecidomyiidae	3L
	Hymenaea cf. *eriogyne* Benth.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	3M

Continue

Table I. Continued..

Host plant family	Host plant species	Galls	Tissue	Side	Shape	Color	Pubescense	Chambers	Likely gall maker	Figures
	Mimosa tenuiflora (Willd.) Poir.	1	Meristem	–	Discoid	Green	Yes	Isolated	Bivalvaemyia pernambucensis Maia (Cecidomyiidae) Maia *et al.* (2010)	3N
		2	Meristem	–	Discoid	Green	No	Isolated	Bivalvaemyia mimosae Maia (Cecidomyiidae) Maia *et al.* (2010)	3O
	Piptadenia moniliformis Benth.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	3P
Lamiaceae	*Hyptis* sp. Jacq.	1	Leaf	Abaxial	Amorphous	Green	Yes	Grouped	Cecidomyiidae	3Q
		2	Leaf	Adaxial	Spheral	Green	No	Isolated	Cecidomyiidae	3R
		3	Leaf	Adaxial	Conical	Green	No	Isolated	Cecidomyiidae	4A
Loranthaceae	*Phthirusa pyrifolia* (Kunth) Eichler	1	Leaf/Stem	Abaxial	Conical	Green	No	Isolated	Cecidomyiidae	4B
Malpighiaceae	*Byrsonima gardneriana* A. Juss.	1	Leaf	Both	Discoid	Green/Red	No	Isolated	Cecidomyiidae	4C
	Byrsonima intermedia A. Juss.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	4D
	Byrsonima sp. Rich. ex Kunth	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	4E
	Heteropterys cf. *anoptera* A. Juss.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	4F
Myrtaceae	*Eugenia* cf. *punicifolia* (Kunth) DC.	1	Leaf	Abaxial	Spheral	Green	No	Isolated	Cecidomyiidae	4G
	Myrtaceae sp. 1	1	Stem	–	Globoid	Brown	No	Grouped	Not identified	4H
	Myrtaceae sp. 2	1	Leaf	Adaxial	Discoid	Green/Red	No	Isolated	Cecidomyiidae	4I
	Psidium guineensis Sw.	1	Leaf (rib)	–	Discoid	Green	No	–	Cecidomyiidae	4J
Nyctaginaceae	*Guapira laxa* (Netto) Furlan	1	Stem	–	Globoid	Brown	No	–	Cecidomyiidae	4K
Phytolaccaceae	*Phytolacca* cf. *thyrsiflora* Fenzl ex J.A. Schmidt	1	Leaf	Abaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	4L
Sapindaceae	*Serjania glabrata* Kunth	1	Leaf	Both	Spheral	Green	No	Isolated	Cecidomyiidae	4M
	Talisia esculenta (A. St.-Hil.) Radlk.	1	Leaf	Abaxial	Spheral	Brown	Yes	Isolated	Cecidomyiidae	4N
	Chrysophyllum gonocarpum (Mart. & Eichler ex Miq.) Engl.	1	Leaf	–	Amorphous	Green	No	Isolated	Heteroptera	4O
	Manilkara dardanoi Ducke	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	4P
Solanaceae	Solanaceae sp. 1	1	Leaf	Adaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	4Q
		2	Stem	–	Globoid	Brown	No	Grouped	Coleoptera	4R
	Solanum cf. *paludosum* Moric.	1	Leaf	Adaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	5A
Malvaceae	*Helicteres velutina* K. Schum.	1	Leaf	Adaxial	Discoid	Green	No	Isolated	Cecidomyiidae	5B
	Waltheria indica L.	1	Leaf	Adaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	5C
Verbenaceae	*Lantana camara* L.	1	Leaf	Adaxial	Spheral	Green	Yes	Isolated	Cecidomyiidae	5D
		2	Stem	–	Elliptical	Green	Yes	–	Not identified	5E
	Lippia gracilis Schauer	1	Leaf	Abaxial	Spheral	Green	No	Isolated	Cecidomyiidae	5F
Not identified	Not identified sp. 1	1	Leaf	Both	Globoid	Green	No	Isolated	Cecidomyiidae	5G
Not identified	Not identified sp. 1	2	Meristem	–	Spheral	Brown	No	Isolated	Cecidomyiidae	5H
Not identified	Not identified sp. 2	1	Leaf	Both	Spheral	Green	Yes	Isolated	Cecidomyiidae	5I
Not identified	Not identified sp. 3	1	Stem/Leaf	–	Amorphous	Brown	No	Grouped	Cecidomyiidae	5J

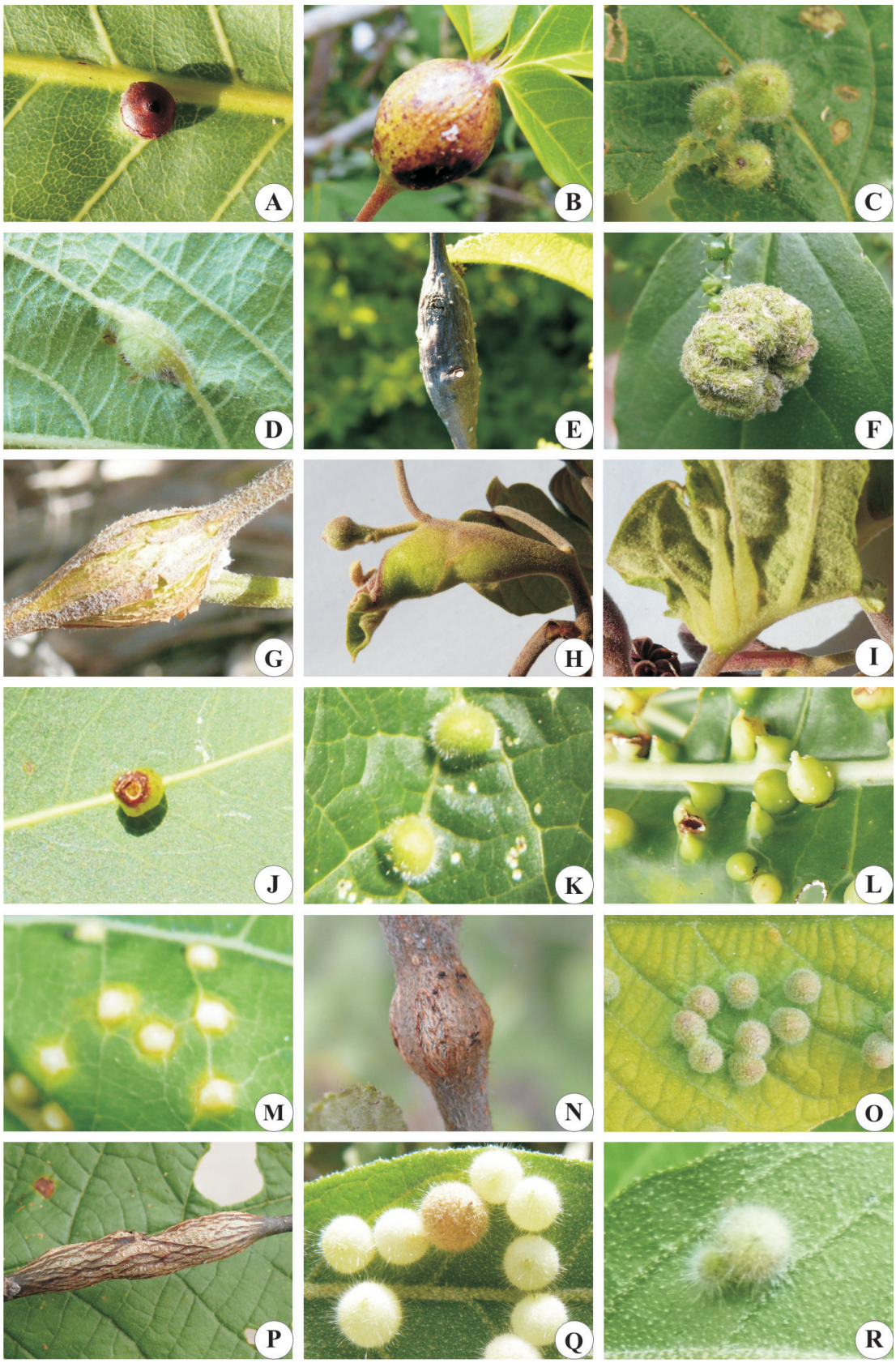

Fig. 2. Galling insect morphospecies in caatinga of Pernambuco, Brazil. A – *Anacardium microcarpum*; B – *Tabebuia impetiginosa*; C–E – *Cordia leucocephala*; F – *Tournefortia rubicunda*; G–I – Convolvulaceae sp. 1; J – *Erythroxylum* cf. *pungens*; K – *Cnidoscolus loefgrenii*; L – *Cnidoscolus phyllacanthus*; M – *Cnidoscolus urens*; N – *Croton adamantinus*; O–P – *Croton blanchetianus*; Q – *Croton echioides*; R – *Croton rhamnifolioides*. For host plant identification and gall morphotypes description, see also Table I.

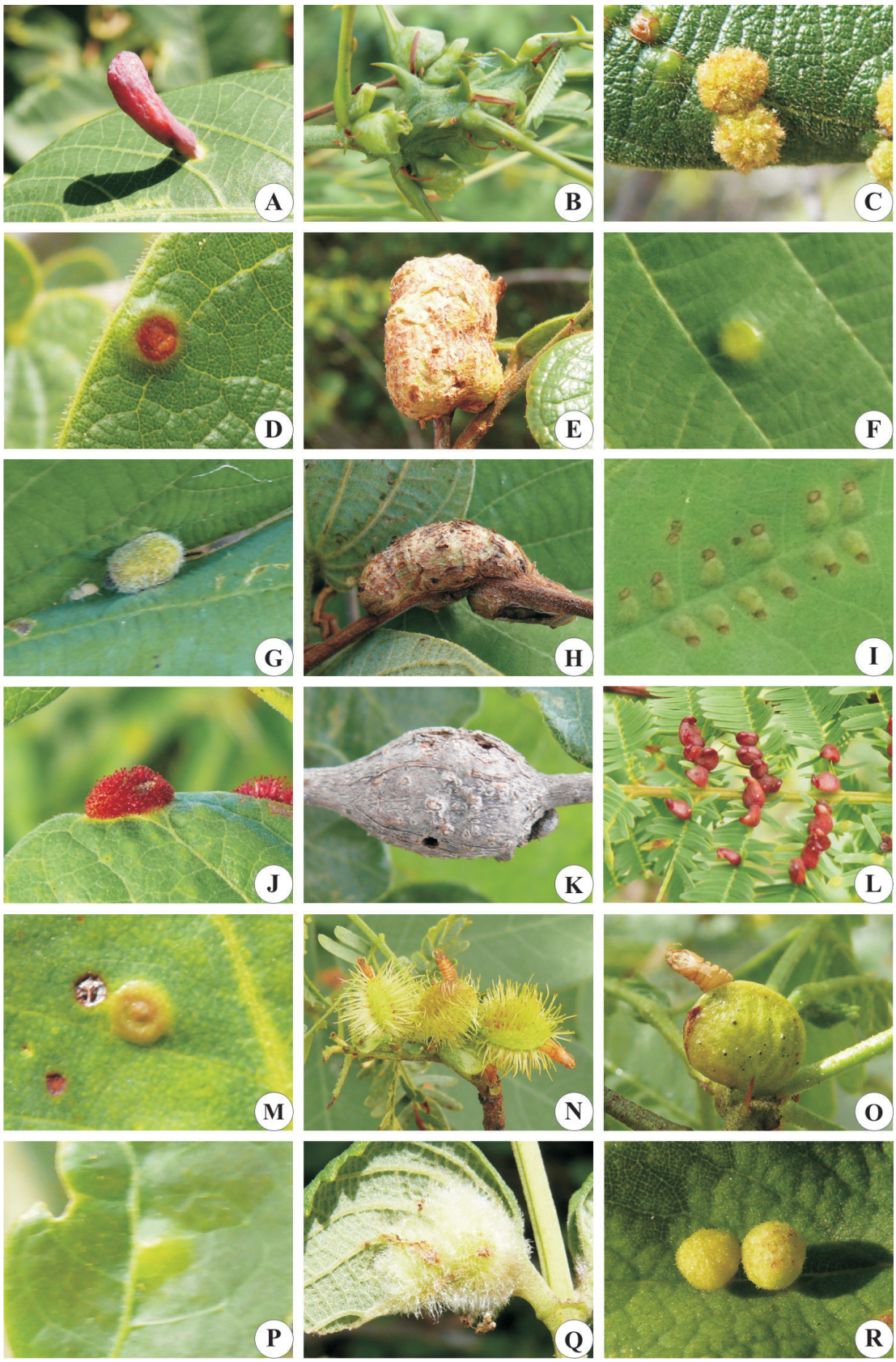

Fig. 3. Galling insect morphospecies in caatinga of Pernambuco, Brazil. A – *Manihot dichotoma*; B – *Acacia* sp.; C–E – *Bauhinia acuruana*; F–I – *Bauhinia cheilantha*; J–K – *Caesalpinia bracteosa*; L – Fabaceae sp. 1; M – *Hymenaea* cf. *eriogyne*; N-O – *Mimosa tenuiflora*; P – *Piptadenia moniliformis*; Q–R – *Hyptis* sp. For host plant identification and gall morphotypes description, see also Table I.

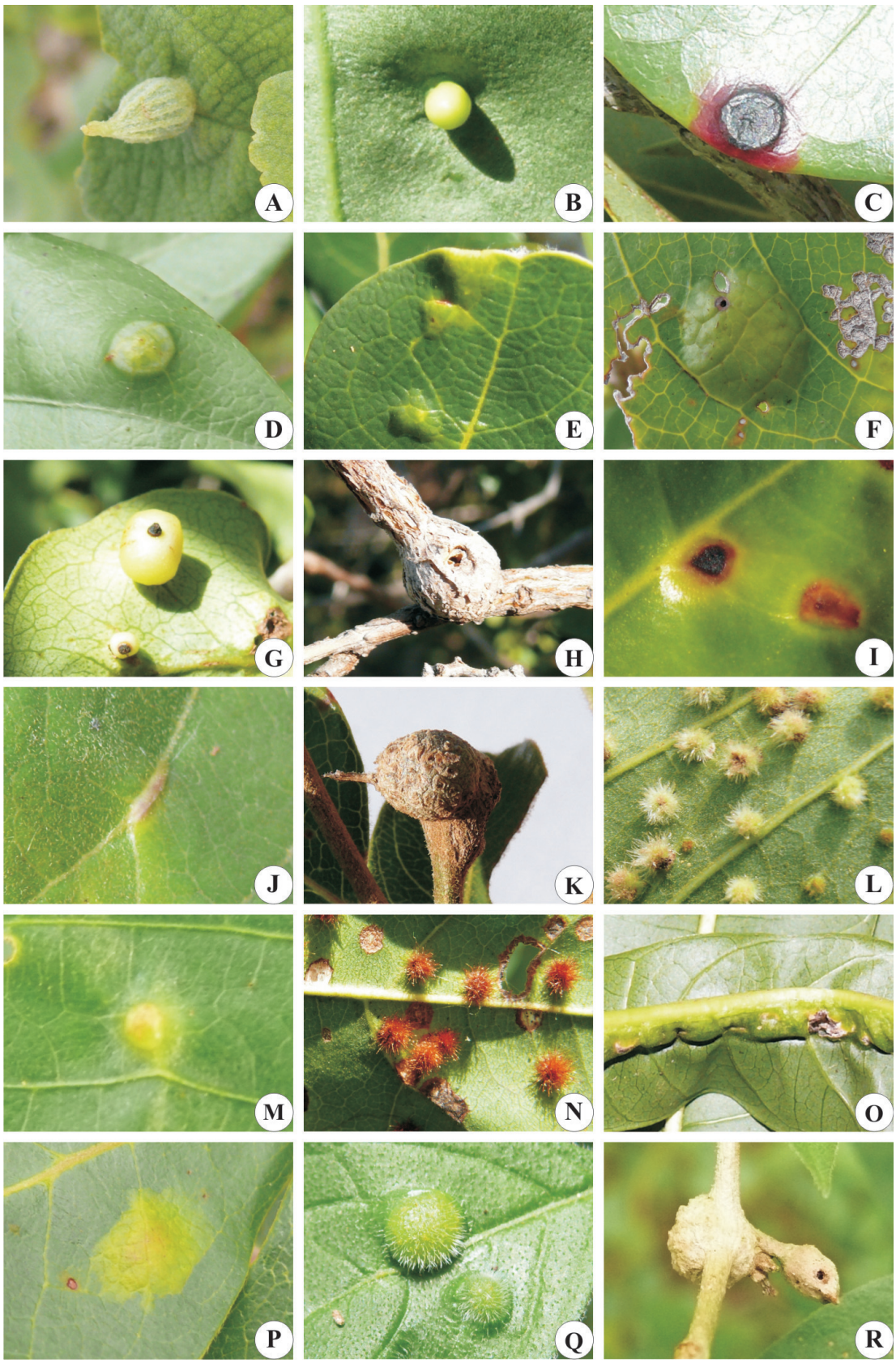

Fig. 4. Galling insect morphospecies in caatinga of Pernambuco, Brazil. A – *Hyptis* sp.;B – *Phthirusa pyrifolia*; C – *Byrsonima gardneriana*; D – *Byrsonima intermedia*; E – *Byrsonima* sp.; F – *Heteropterys* cf. *anoptera*; G – *Eugenia* cf. *punicifolia*; H – Myrtaceae sp. 1; I – Myrtaceae sp. 2; J – *Psidium guineensis*; K – *Guapira laxa*; L – *Phytolacca* cf. *thyrsiflora*; M – *Serjania glabrata*; N – *Talisia esculenta*; O – *Chrysophyllum gonocarpum*; P – *Manilkara dardanoi*; Q–R – Solanaceae sp. 1. For host plant identification and gall morphotypes description, see also Table I.

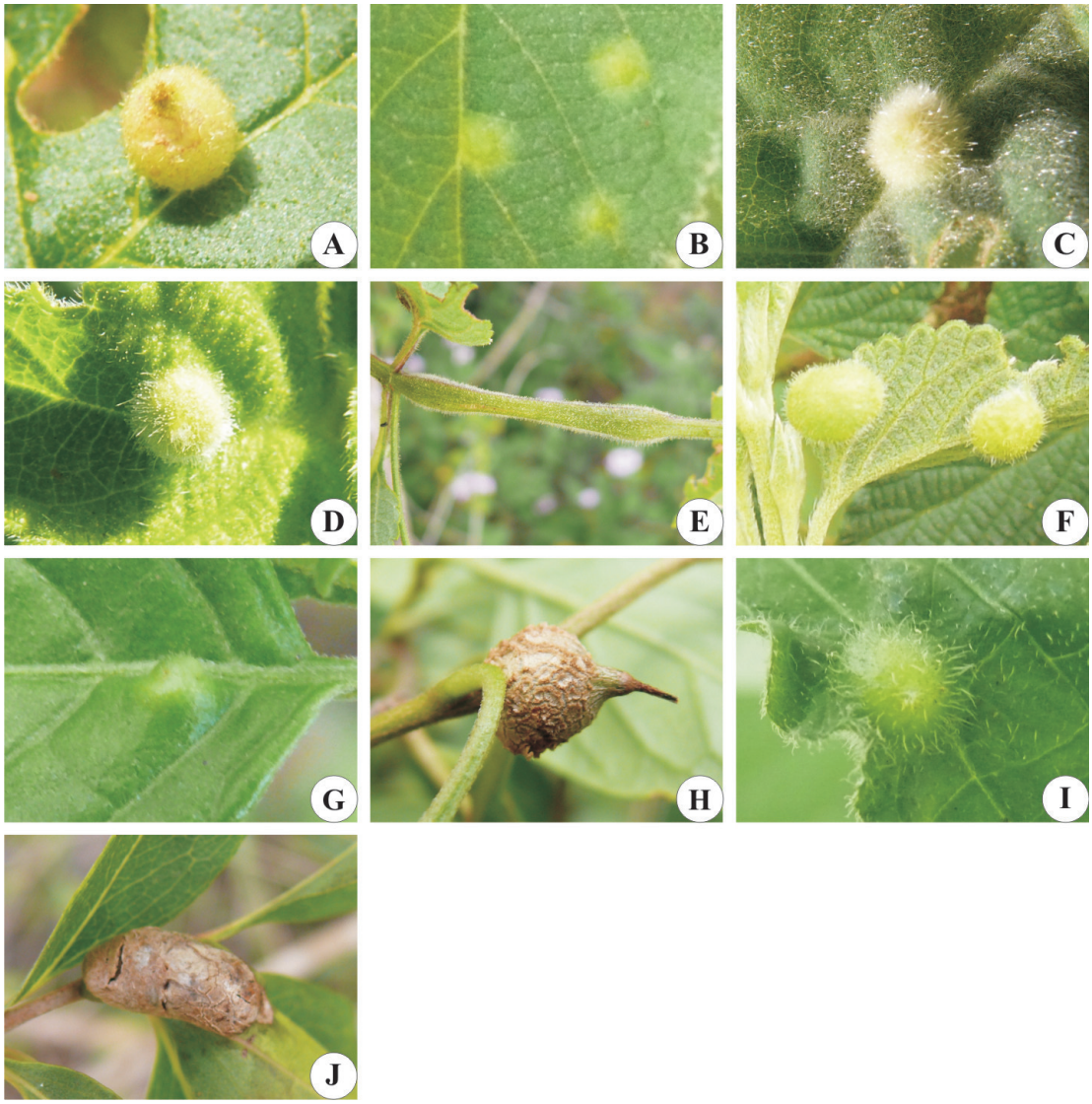

Fig. 5. Galling insect morphospecies in caatinga of Pernambuco, Brazil. A – *Solanum* cf. *paludosum*; B – *Helicteres velutina*; C – *Waltheria indica*; D–E – *Lantana camara*; F – *Lippia gracilis*; G–H – Not identified sp. 1; I – Not identified sp. 2; J – Not identified sp. 3. For host plant identification and gall morphotypes description, see also Table I.

DISCUSSION

Most studies conducted in Brazil with description of insect galls are concentrated in the cerrado (savanna) (e.g., Fernandes *et al.* 1997; Gonçalves-Alvim & Fernandes 2001a, b; Lara *et al.* 2002; Urso-Guimarães *et al.* 2003; Maia & Fernandes 2004; Urso-Guimarães & Scarelli-Santos 2006; Carneiro *et al.* 2009b; Coelho *et al.* 2009) and this one represents the first contribution o the understanding on this guild distribution and diversity in the caatinga vegetation. Based on the present results of galling insects and their host plants in the caatinga we attempt some generalizations. The low richness of galling species in the caatinga (64 morphospecies) was more similar with the seasonally dry tropical forest in Serra do Cipó located in the southern range of the Espinhaço Mountains, which investigators found 92 distinct gall morphotypes on several organs of 51 host plant species of 19 families (Coelho *et al.* 2009). However, this comparison is not conclusive because in another dry forest of northern Minas Gerais (Jequitinhonha Valley), Fernandes *et al.* (1997) reported 236 species of galling insects. A comparison with the data from another Brazilian ecosystems (Atlantic rain forest, cerrado, Amazon rain forest), indicates that the richness of the insect galls in the caatinga is comparatively smaller. The richness of galling species in the Atlantic rain forests of the Vale do Rio Doce was represented by 273 galling species (Fernandes *et al.* 2001), and in the central Amazonia, Julião *et al.* (2005) reported on 246 and 302 galls morphotypes on the canopy of a seasonally flooded forest of igapo and varzea, respectively. It is clear in these comparisons that we need more data on the caatinga and on others wet and dry tropical forests in a near future to better understand the evolution and

biogeography of galling insects in Brazil, and to construct a general pattern of species richness.

Different hypotheses have been proposed to explain variation in abundance and diversity of galling species. According to Fernandes & Price (1988, 1991, 1992), the harsh environment hypothesis predicts that galling species richness will be higher in dry and hygrothermically stressed environments, and in Brazil, based on this hypothesis, the caatinga had higher richness than other wet ecosystems. Preliminary, our results not corroborated this hypothesis because that caatinga was poorer in species of galling insects than other areas; however, this hypothesis must be tested further. One study supports a low diversity of galling insects in dry forest (29 galling species in an Argentinean Chaco, semi-arid region very similar to caatinga, see Fernandes *et al.* 2002; and 92 galling species in dry forest of cerrado, see Coelho *et al.* 2009).

Although the purpose of this study is not to compare the richness of galling insects among sample areas, it is important to emphasize that the Vale do Catimbau showed approximately half (33 morphotypes) of all species found in this survey. This pattern could be produced by the atypical vegetation of this valley, whose revealed a plant species pattern different from those of the caatinga in Northeastern Brazil, with part of its flora presents the geographical distribution covering open vegetation formations such as cerrado, rupestrian fields and others (see Rodal *et al.* 1998).

This is the first study on galling insect richness done in the caatinga. However, other caatinga areas, in other Brazilian states should be sampled in order to reach a better understanding of the distribution of galling insects and their host plants along the gradient of this dry forest due to the territorial extension of this semi-arid vegetation. This study constitutes a unique data set that reinforce the need to survey in tropical dry forests to better comprehend gall-forming insect distribution patterns.

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