



A synopsis of fern galls in Brazil

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Abstract: Galls are neo-formed plant structures induced by species-specific interaction between an inducing organism and a host plant. Lycophytes and ferns are two distinct plant lineages historically lumped together as pteridophytes. A number of authors suggest low gall frequency in lycophytes and ferns, compared to angiosperms. This study aimed at compiling an updated overview of fern galls in Brazil, providing information on hosts, gall-inducing organisms and associated fauna. The synopsis was compiled using existent data and by updating scientific names and gathering new information obtained by the authors in fieldwork. To date, galls have been recorded on 16 fern species but none on lycophytes. However, the inducer was identified at species level in only three gall morphotypes from three fern species, with a doubtful inducer for *Pteridium* sp. Galls are induced by mites (Eriophyidae) and insects of the orders Diptera, Lepidoptera, Thysanoptera, and Hemiptera, Cecidomyiidae (Diptera) being the most frequent galler insect.

Keywords: Pteridophytes, lycophytes, galls, Neotropical, Cecidomyiidae.

Sinopse de galhas em samambaias no Brasil

Resumo: Galhas são estruturas vegetais neoformadas induzidas por interações espécie-específicas entre um organismo indutor e uma planta hospedeira. Licófitas e samambaias são duas linhagens de plantas historicamente classificadas juntas como pteridófitas. Diversos autores sugerem que há uma baixa frequência de galhas em licófitas e samambaias, em comparação com as angiospermas. Este trabalho tem como objetivo fornecer um panorama atualizado sobre as galhas em samambaias no Brasil, disponibilizando informações sobre espécies hospedeiras, galhadores e fauna associada. A sinopse foi realizada compilando-se os dados existentes, atualizando os nomes científicos e agregando informações novas obtidas pelos autores em trabalhos de campo. Até o momento, foram registradas galhas em 16 espécies de samambaias e nenhum registro em licófitas. Contudo, em apenas três morfotipos de galhas, de três espécies de samambaias, o indutor foi identificado a nível de espécie, com um indutor duvidoso para *Pteridium* sp. As galhas são induzidas por ácaros (Eriophyidae) e insetos das ordens: Diptera, Lepidoptera, Thysanoptera, Hemiptera, sendo Cecidomyiidae (Diptera) o galhador mais frequente.

Palavras-chave: Pteridófitas, licófitas, galhas, Neotropical, Cecidomyiidae.

Introduction

Lycophytes and ferns are two distinct plant lineages historically lumped together under various terms, such as “pteridophytes” or “ferns and allied plants” (Smith et al. 2006, PPG I 2016). Interactions between lycophytes, ferns and arthropods, especially in the Neotropical region, are poorly documented, little known and even neglected.

Galls, characteristic neo-formed plant structures created by hyperplasia and cellular hypertrophy that can occur in different plant organs, are generated by species-specific interactions between an inducing organism and a host plant (Mani, 1964; Isaias et al. 2013). While some authors claim that galls can be induced by bacteria, fungi, nematodes, mites and insects (Mani, 1964), others state that

their induction is restricted to nematodes, insects and mites (Raman, 2007). Inducers establish a parasitic relationship and manipulate the metabolism of the host plant (Mani 1964, Raman, 2007).

A number of authors suggest low gall frequency in lycophytes and ferns, compared with angiosperms (Mehlreter et al. 2010). The chapter entitled Zooecidium, published in 1938 in the Manual of Pteridology, is an important review of lycophyte and fern galls (Docters van Leeuwen 1938). Recently, for the Neotropical region, Hanson & Gómez-Laurito (2005) recorded 18 species of ferns with galls in Costa Rica.

The aim of this study was to perform an updated overview of fern galls in Brazil, providing information on host species, gall-inducing insects and associated fauna.

Material and Methods

The synopsis was compiled using existing data, and by updating scientific names and gathering new information obtained by the authors in fieldwork.

Data concerning lycophyte and fern galls were collected from historic reference studies (Houard 1933), in the catalogue of Cecidomyiidae of the world (Gagné & Jaschhof 2017); in 55 articles from inventories of insect galls in Brazil published between 1988 and 2017 and studies carried out exclusively with fern galls (Kraus et al. 1993, Martins & Pimenta 1988, Brown et al. 2004, Maia & Santos, 2011, 2015, Farias et al. 2018).

Lycophyte and fern nomenclatures were updated using the Flora do Brasil 2020 database and the PPG I classification system (2016).

Complementary data were obtained in fieldwork aimed at collecting fern galls in the Atlantic Forest in the following locations: Itatiaia National Park, Serra dos Órgãos National Park, Maricá Environmental Protection Area, Serra do Barbosão Municipal Nature Park (all in Rio de Janeiro state), Campos do Jordão (São Paulo state) and Tiradentes (Minas Gerais state). A total of 12 collections were carried out between 2011 and 2017. All the gall morphotypes were photographed, collected and taken to the laboratory where part of the sample was dissected, in order to obtain immature gall-inducing insects and determine the inducer taxon. Another part was packed in covered plastic pots, labeled and inspected daily until gall rot occurred, to obtain adult gall-inducing insects. Gall shapes were standardized in accordance with Isaias et al. (2013). All the biological material was deposited in the entomological collection of the National Museum (MNRJ) of the Federal University of Rio de Janeiro (UFRJ) and Herbarium of the Teacher Training Faculty (FFP) of Rio de Janeiro State University (UERJ).

Results and Discussion

The first records of fern galls in Brazil were made by Houard (1933). This author reported six gall morphotypes in five fern species (Table 1). In none of these the inducer was identified at a specific level, one gall was mite-induced (Eriophyidae) and five by the orders Diptera, Hemiptera and Thysanoptera. In *Nipidium crassifolium*, Houard (1933) found that the inducer is a Coccidae (Hemiptera); Maia & Mascarenhas (2017) also recorded globoid gall morphotype on the adaxial side of the leaves of this fern (Figs. 1 E-F). However, other insects, including inquiline (Psocoptera, Sciaridae: Diptera and *Corythaica cyathicollis* (Costa, 1864) Tingidae: Hemiptera), parasitoids (Platygastridae: Hymenoptera) and an unidentified Diptera larva (likely the galler) were found in recent field studies, which raises doubts about the true identity of the inducer. Some species of Platygastridae (Hymenoptera) parasitize Cecidomyiidae galls (Johnson et al. 2013). Our group is conducting more detailed analyses in an attempt to clarify this issue.

According to Martins & Pimenta (1988), *Dolichophaonia gallicola* (Diptera, Muscidae) is the gall-inducing insect of *Pteridium aquilinum* (Table 1). However, Monteiro & Oda (1999) question whether this muscid is the gall inducer. These authors argue that the inducer is an inquiline and not a cecidogenous species, since it exhibits the buccal apparatus of a predator.

Kraus et al. (1993) conducted anatomical studies on stem galls of *Microgramma squamulosa* induced by a microlepidoptera (Gelechiidae: Lepidoptera). Later, Brown et al. (2004) described it as a new species: *Tortrimosaica polypodivora* (Tortricidae: Lepidoptera). (Figure 1L).

More recently, Maia & Santos (2011, 2015) recorded two stem gall morphotypes in *Microgramma vacciniifolia*, one ellipsoid-shaped (fusiform) induced by the microlepidoptera *Tortrimosaica polypodivora* (Figure 1A), and the other spherical (globoid) and induced by the Cecidomyiidae: Diptera *Primadiplosis microgrammae* (Figure 1B). Two species of parasitoid wasps (Hymenoptera) were also observed: Torymidae and Tetrastichinae (Eulophidae). In microlepidoptera-induced galls a parasitoid wasp Cheloninae (Braconidae) was also recorded, in addition to an inquiline species of *Dasineura* sp. (Cecidomyiidae: Diptera). In recent fieldwork, a new gall morphotype was recorded for species of *Microgramma squamulosa* and *M. vacciniifolia*. It is a conical and lenticular leaf gall respectively, with a white waxy layer at the opening on the abaxial side of the leaf, whose inducer remains undetermined (Figures I-J).

Maia et al. (2008) recorded a leaf gall on *Cyathea* sp., without identifying its inducer. In field studies conducted in Itatiaia National Park, a globoid leaf gall not yet identified, induced by Cecidomyiidae (Diptera), was found on *Cyathea dichromatolepis* (Figure 1C). A lenticular leaf gall induced by a new species of Cecidomyiidae was recorded on *Cyathea phalerata* in the Atlantic Forest of Pernambuco state, Brazil (Farias et al. 2018).

Leaf galls were recorded on *Pleopeltis hirsutissima* (Figure 1D), *Pleopeltis minima*, *Serpocaulon catharinae* and *Campyloneurum nitidum* (Figures 1G-H). In the first two species, the morphotype is globoid and induced by Cecidomyiidae (Diptera). In the third fern species the gall is conical and in the last lenticular, both with a white waxy layer at the opening on the abaxial side of the leaf. However, we were unable to identify the inducers. Witches' broom galls on leaves of *Dicranopteris flexuosa* was registered, probably induced by mites.

The leaves are the most frequently attacked organ and the shape of the gall is predominantly globoid. The galls are induced by mites (Eriophyidae) and insects of the orders Diptera, Lepidoptera, Thysanoptera and Hemiptera, Cecidomyiidae (Diptera) being the most frequent gall-inducing insect. In other parts of the world, there are records of fern galls induced by Hymenoptera (Balick et al. 1978, Houard 1908, 1933, Docters van Leeuwen, 1938, Bera et al. 2003) and Coleoptera (Docters van Leeuwen 1938, Bera et al. 2003).

There are no specific inventories for the lycophyte and fern galls of different ecosystems worldwide. The most important data are from Costa Rica, where galls were recorded on only 18 of the 1,120 fern species cataloged, that is a ratio of 0.016 (no. of ferns with galls/no. of ferns species) (Hanson & Gómez-Laurito 2005). In Brazil, galls have been recorded on 16 of the 1,144 fern species cataloged (Flora do Brasil 2020), a ratio of 0.013. However, the inducer was identified at species level in only three gall morphotypes from three fern species (Maia & Santos 2011, 2015). To date, no lycophyte species have been recorded as hosting galls in Brazil and Costa Rica. However, there are records of five Selaginellaceae species from India, New Guinea, Germany and the Malay Peninsula (Alston 1945, Docters van Leeuwen 1938, Mani 1964, Patra et al. 2009).

Fern galls in Brazil

Table 1. Synopsis of fern galls in Brazil. MG: Minas Gerais state, RJ: Rio de Janeiro state, SP: São Paulo state.

Family	Host species	Organ with gall	Gall shape	Gall-inducing insect	Location	Reference
Blechnaceae	<i>Salpichlaena volubilis</i> (Kaulf.) J.Sm. *1	Leaf	Leaf roll	Eriophyidae	Not indicated	Houard (1933)
Cyatheaceae	<i>Cyathea dichromatolepis</i> (Fée) Domin	Leaf	Globoid	Cecidomyiidae (Diptera)	Itatiaia National Park, RJ	This publication
	<i>Cyathea phalerata</i> Mart.	Leaf	Lenticular	Cecidomyiidae (Diptera)	Pernambuco state	Farias et al. (2018)
	<i>Cyathea</i> sp.	Leaf	---	Not identified	Restinga de Bertioga State Park, SP	Maia et al. (2008)
Dennstaedtiaceae	<i>Pteridium</i> sp.*2	Leaf (Rachis)	Fusiform	<i>Dolichophaonia gallicola</i> (Albuquerque, 1958) (Diptera, Muscidae)*7	Belo Horizonte, MG	Martins & Pimenta (1988)
Gleicheniaceae	<i>Dicranopteris flexuosa</i> (Schrad.) Underw.	Leaf	“Witches’ broom”	Mite?	Tiradentes, MG	This publication
Hymenophyllaceae	<i>Hymenophyllum hirsutum</i> (L.) Sw.*3	Stem (Rhizome)	Globoid	Diptera	Not indicated	Houard (1933)
	<i>Hymenophyllum pulchellum</i> Schlttdl. & Cham. *4	Stem (Rhizome)	Globoid	Diptera	Not indicated	Houard (1933)
		Leaf	Globoid	Diptera	Not indicated	Houard (1933)
Polypodiaceae	<i>Campyloneurum nitidum</i> (Kaulf.) C. Presl	Leaf	Lenticular	Not identified	Serra dos Órgãos National Park, RJ	This publication
	<i>Microgramma squamulosa</i> (Kaulf.) de la Sota	Stem (Creeping)	Fusiform	<i>Tortrimosaica polypodivora</i> Brown & Baixeras, 2004 (Tortricidae, Lepidoptera)	São Paulo, SP	Kraus et al. (1993) Brown et al. (2004)
		Leaf	Conical	(Cecidomyiidae, Diptera)	Nova Friburgo, RJ Campos do Jordão, SP Nova Friburgo, RJ	This publication This publication
	<i>Microgramma vacciniifolia</i> (Langsd. & Fisch.) Copel.	Stem (Creeping)	Globoid	<i>Primadiplosis microgrammae</i> Maia, 2011 (Cecidomyiidae, Diptera)	Maricá Environmental Protection Area, RJ	Maia & Santos (2011, 2015) Gagne & Jaschhof (2014)
		Stem (Creeping)	Fusiform	<i>Tortrimosaica polypodivora</i> (Tortricidae, Lepidoptera)	Maricá Environmental Protection Area, RJ	Maia & Santos (2015)
		Leaf	Lenticular	Cecidomyiidae, Diptera	Serra do Barbosão, RJ	This publication
	<i>Niphidium crassifolium</i> (L.) Lellinger *5	Leaf	Clavate	Coccidae (Hemiptera)	Not indicated	Houard (1933)
				Not identified	Itatiaia National Park, RJ	Maia & Mascarenhas (2017)
				Not identified (Diptera?)	Itatiaia National Park, RJ Serra dos Órgãos National Park, RJ	This publication
		<i>Pleopeltis hirsutissima</i> (Raddi) de la Sota	Leaf	Globoid	Cecidomyiidae, Diptera	Serra dos Órgãos, RJ
	<i>Pleopeltis minima</i> (Bory) J. Prado & R.Y. Hirai	Leaf	Globoid	Cecidomyiidae, Diptera	Niterói, RJ	This publication
	<i>Serpocaulon catharinae</i> (Langsd. & Fich.) A.R. Sm.	Leaf	Conical	Not identified	Serra dos Órgãos National Park, RJ Itatiaia National Park, RJ Minas Gerais, MG	This publication Rosy Isaias (Personal communication)
	<i>Serpocaulon</i> sp. *6	Leaf	Lenticular	Thysanoptera*8	Not indicated	Houard (1933)

Name used in the original reference: *1-*Blechnum volubile* Kaulf.; *2-*Pteridium aquilinum* (L.) Kuhn; *3-*Hymenophyllum ciliatum* (Sw.) Sw.; *4-*Hymenophyllum lineare* Sw. var. *brasiliense* Rosenstock; *5-*Polypodium crassifolium* L. (em Houard 1933); *6-*Polypodium* sp.; *7-*Phaonia gallicola* Albuquerque, 1958; *8-*Thripsidae*.



Figure 1. Fern galls in Brazil. a-b *Microgramma vacciniifolia*. a - Gall induced by *Tortrimsaica polypodivora* (Lepidoptera). b - Gall induced by *Primadiplosis microgrammae* (Cecidomyiidae-Diptera). c - *Cyathea dichromatolepis*. d - *Pleopeltis hirsutissima*. e-f *Niphidium crassifolium*, e - adaxial side of the leaf, f - abaxial side of the leaf. g-h *Campyloneurum nitidum*. g - adaxial side of the leaf, h - abaxial side of the leaf. i-j *Microgramma squamulosa*. i-j-gall induced by Cecidomyiidae(Diptera). i - adaxial side of the leaf, j - abaxial side of the leaf. i-l *Tortrimsaica polypodivora* (Lepidoptera). All photos by Marcelo Guerra Santos except photo "d" by Alene Ramos Rodrigues.

The estimated number of ferns worldwide is 10,578 species (PPG I). In line with the methodology used by Espírito-Santo & Fernandes (2007) and the data collected to date from Brazil and Costa Rica, we estimate an average of 153 fern species with galls worldwide. According to Espírito-Santo & Fernandes (2007), the Neotropical region is the least studied for galls, despite its substantial plant richness. As such, these values are likely underestimated.

Espírito-Santo & Fernandes (2007) suggest that for angiosperms there is a positive correlation between gall-inducing insects and plant richness. These authors also underscore the presence of “superhost plants”, which may confirm a high richness of gall-inducing insects. In Brazil, the greatest gall richness was recorded for the genus *Cyathea*, with three species and the family Polypodiaceae, with 10 morphotypes in eight fern species. Three gall morphotypes were recorded in *Microgramma vacciniifolia* (Table 1).

The present synopsis systematized and broadened the records of fern galls in Brazil, thereby contributing to the knowledge of these interactions worldwide. The biological difficulties in obtaining adult insects precluded identifying their specific level or order. In some cases, the identity of the galler remains unknown. However, the information presented here is important in designing future studies on the interactions between ferns and insects, especially those involving galls.

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Author's Contribution

Marcelo Guerra Santos: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Valéria Cid Maia: Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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