**PLANT ARCHITECTURE AND GALL ABUNDANCE ON TWO PLANT SPECIES FROM MARICÁ RESTINGA, RJ, BRAZIL**

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Running title: *Plant architecture and gall abundance in Maricá Restinga*

**Abstract:** Several hypotheseshave been proposed to explain the distribution pattern and abundance of herbivorous insects on its host plants. For instance, the plant architecture hypothesis predicts that architecturally complex plants present greater herbivorous diversity. This study aimed to test the plant architecture hypothesis and its relation with gall abundance on two Brazilian endemic plant species, *Clusia lanceolata* (Clusiaceae) and *Monteverdia obtusifolia* (Celastraceae) in Maricá Restinga, Rio de Janeiro. During September and November 2017, 30 individuals from each plant species were selected for the characterization of architectural parameters (height, soil height circumference, number of second and third level ramifications, treetop area, plant volume, and leaf number) and gall abundance. A total of 922 insect galls were registered on *C. lanceolata* and 1.139 on *M. obtusifolia*. Variations did not explain gall abundance for both plant species. Architectural parameters can be masked by the quantity of undifferentiated tissue available. Architecturally more complex plants do not necessarily offer greater quantity of undifferentiated tissue if are not during regrowth period, so that the unavailability of these tissues may standardize the response of architecturally distinct plants.

**Keywords:** gall inducing insects; super-host; architectural complexity; Atlantic Forest

**INTRODUCTION**

Insect galls are structures formed by cellular multiplication (hiperplasy) and/or increase in cellular size (hypertrophy). They are known for providing shelter and food to its inductors. A few studies focusing on gall induction, have already verified that it is the insect which determines the gall morphology, and moreover, these inductors redirect the nutritional tissue production for their own benefit (Cook and Gullan 2008). Therefore, galling insects are considered the most sophisticated and specialized in relation to host plants (Schoonhoven *et al*. 2005, Shorthouse *et al*. 2005). Galls are important elements for the identification of ecological patterns and processes because they constitute units, delimited in time and space, they are easy for sampling and have species-specific relation with their host plant (Fernandes *et al*. 1996, Price *et al*. 1998, Stone & Schönrogge 2003, Fagundes *et al*. 2005).

Many studies have been looking to explain the distribution and abundance patterns of galling insects and what are the mechanisms generating these patterns Price *et al*. 1998, Mendonça 2001, Carneiro *et al*. 2014). For such, several hypothesis have been proposed, including the plant architecture hypothesis (Lawton 1983), which predicts greater gall richness and abundance on plants with grater structural complexity, that is, larger plants, with more branches ad more leaves. These plants, besides having more visibility, can offer to the galling insect greater resource availability and greater number of oviposition sites, as well as lower risk of attack by parasitoids (Lawton 1983, Fernandes & Price 1988, Collevatti & Sperber 1997). It is noteworthy that these hypotheses were elaborated from data obtained in temperate environments, with the possibility that tropical systems do not strictly follow these patterns (Cornelissen & Fernandes 2001).

According to Espírito-Santo *et al*. (2007), plant architecture is usually a relevant factor influencing the abundance and distribution of herbivores. However, the determinant traits of the plant may vary among studies depending on the life history of the species involved. As a result of the sessile habit, galling insects depend upon young undifferentiated tissue availability for the induction and development of the galls (Mani 1964, Rohfritsch 1992). Therefore, plant architectural traces may have stronger effects upon this guild when compared to free-living insects, which can leave the plant.

Five main components are established as measurements of plant architecture: size, growth form (herbs, shrubs and trees), seasonal development, variety and persistence of the aerial parts (Lawton 1983). Although the ramification pattern (Marquis *et al*. 2002, Espírito-Santo *et al*. 2007), the number of active stems (Larson & Whitham 1997), the height of the plant (Gonçalves-Alvin *et al*. 1999) and crown volume (Alonso & Herrera 1996, Fagundes & Gonçalves 2005) have also been used as architectural measurements (Price *et al*. 1998, Veldtman & McGeoch 2003, Cuevas-Reyes *et al*. 2004a,b, Carneiro *et al*. 2005, Espírito-Santo *et al*. 2007, Lara *et al*. 2008, Costa *et al*. 2010, Silva *et al*. 2017).

In this context, the main goal of this study is to test the plant architectural hypothesis and its relation with gall abundance on two plant species endemic to Brazil, *Clusia lanceolata* Cambess. (Clusiaceae) and *Monteverdia obtusifolia* (Mart.) Biral (Celastraceae) in Maricá Restinga, Rio de Janeiro. Thus, we expect that *C. lanceolata* and *M. obtusifolia* individuals with more complex architecture present greater gall abundance. This is the first study approaching plant architecture and gall abundance in a Restinga environment in Brazil.

**MATERIALS AND METHODS**

*Study area*

The field research was accomplished in August 2017 on a protected area, Área de Proteção Ambiental de Maricá (22°57’42”S/ 42°51’54”W), located in Maricá municipality, Rio de Janeiro, southeast Brazil (Figure 1). The area comprises about 800 hectares of Restinga vegetation (Silva 2011), including 379 plant species and nearly 100 species of galling insects (Silva & Oliveira 1989, Maia 2001).

*Species of the study*

*Clusia lanceolata* Cambess. and *Monteverdia obtusifolia* (Mart.) Biral are perennial shrubs or small trees with high frequency and great abundance in the study area (Maia 2001).

*Clusia lanceolata* (Figure 2a) is an ornamental plant, especially when in blossoms, so it is frequently used in landscaping (Lorenzi 2009). It exclusively occurs in the Atlantic Rain Forest, and its geographical distribution is very restricted, including only three states from the Brazilian Southeast region: Espírito Santo, Rio de Janeiro and São Paulo (Flora do Brasil 2020). It hosts two gall morphotypes, both on leaves, one induced by an unidentified Lepidoptera species, rare and occurring in low abundance (Maia 2013) and other induced by *Clusiamyia nitida* Maia 1996 (Diptera, Cecidomyiidae) which is very abundant, common and occurs throughout the year (Figure 2b) (Maia 2001).

*Monteverdia obtusifolia* has anti-inflammatory properties and anti-ulcer effects (Figure 2c). Moreover, its wood is used for tool construction and firewood. The species occurs in the Atlantic Rain Forest and the Amazon Forest, and its geographical distribution is broader, including the North regions (Pará), Northeast (Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Rio Grande do Norte and Sergipe) and Southeast (Espírito Santo, Rio de Janeiro, São Paulo). *Monteverdia obtusifolia* hosts two gall morphotypes, one on fruits induced by *Bruggmanniella maytenuse* Maia & Couri 1992 and the other on leaves induced by *Mayteniella distincta* Maia 2001 (Figure 2d), the firs is very rare, while the second is common and abundant (Maia 2001). Both galls are induced by the Cecidomyiidae mosquito family.

*Experimental design*

In the months of September and November 2017, 30 individuals of each plant species were randomly chosen in the studied area. For each individual the following parameters were measured: height, CAS (soil height circumference), number of second (2º level) and third (3º level) level ramifications (Espírito-Santo *et al*. 2007), treetop area, plant volume and number of leaves from 10 terminal branches. Plant volume was measured through the cone volume formula V=[(π.r2.h)/3], and the treetop area through the ellipse area A=(π.a.b/4) where “a” and “b” are the larger and smaller widths respectively (Cintrón & Schaeffer-Novelli 1984) . Each morphotype abundance was determined through its direct counting in 10 terminal branches from each treetop plant, totaling 300 branches per species.

*Statistical analyzes*

The plant architecture effect on gall abundance was evaluated through general linear models (GLM) with Poisson errors. Since this model was over-dispersed we used a negative binomial GLM, a commonly used distribution for such cases (Hilbe 2011). Given that the number of ramifications of second and third level variables, height and volume and height and treetop variables were too correlated, we included in the model only the height, number of second level ramifications and treetop. Analyses were performed with the R software (R DEVELOPMENT CORE TEAM 2016).

**RESULTS**

For *C. lanceolata* individuals, 922 galls were registered on 2496 leaves with an average of 31 galls per individual, varying from 1 to 73. Plant height varied from 0,6 to 4,9 m (2,06 ± 1/ mean ± standard deviation), CAS varied from 0,05 to 0,6 m (0,15 ± 0,14), number of ramifications: 2º level from 1 to 8 (4 ± 1,94) and 3º level from 3 to 15 (6 ± 2,69), treetop from 0,06 to 2,01 m2 (0,52 ± 0,49), volume from 0,26 to 41,68 m3 (8,07 ± 11,27) and leaf number varied from 40 to 175 (83,2 ± 26,44) per plant.

For *M. obtusifolia,* 1139 galls were registered on 3010 leaves with an average of 38 galls per individual, varying from 0 to 254. Five plants were registered without galls. Plant height varied from 0,9 to 4,44 m (2,24 ± 0,97), CAS from 0,06 to 0,33 m (0,16 ± 0,09), the number of ramifications varied: 2º level from 1 to 6 (4 ± 1,5) and 3º level from 2 to 12 (6 ± 2,46), treetop from 0,04 to 1,73 m2 (0.5 ± 0,42), volume from 0,27 to 41,01 m3 (7,71 ± 9,24) and the number of leaves varied from 64 to 154 (100,3 ± 24,6) per plant.

The variables did not explain the gall abundance for both studied species (Table 1). Thus, the number of galls did not respond to the increase of height, soil height circumference, treetop area and volume, that is, plant size. In this same way, the complexity characterized by the presence of secondary and tertiary branches and leaf number, did not influence the abundance of the insects.

**DISCUSSION**

The hypothesis of plant architecture encompasses two other hypotheses. The first one suggests that plant size may have a positive effect on insect diversity due to the effect of the area per se (Strong *et al*. 1984). The other considers that larger plants offer more resources, because they have more oviposition sites and because they are more apparent to the gall inducers.

In the present study, variables did not explain gall abundance on both studied species. Costa *et al*. (2010) also did not observe significant relation between gall diversity associated to *Copaifera langsdorffii* Desf. (Fabaceae) and the size or ramification pattern of the host plant. The authors rely on the predictability of the resource and galling specificity to support the results. In fact, if a single tree supports most of the galling insects due to resource predictability and the galling specialist habit, it would be expected that plant architecture could explain very little of the total variation.

Other studies showed that plant architecture has partially influenced gall richness and abundance (Lara *et al*. 2008, Costa *et al*. 2010, Silva *et al*. 2017). Lara *et al*. (2008) partially corroborated the plant architecture hypothesis finding correlation between number of galls and number of branches and biomass, but not with number of sprouts and leaves of thehost plant *Macairea radula* DC. (Melastomataceae).

However, there are some studies where a positive relation between the increase of host plant complexity and the galling insect diversity were found (Alonso & Herrera 1996, Marquis *et al*. 2002, Espírito-Santo *et al*. 2007, Woodcock *et al*. 2007, Araujo & Santos 2009, Silva *et al*. 2017). Silva *et al*. *et al*. (2017) have shown that the plant structural complexity has a significant influence on the number of galls on *Avicennia germinans* L. (Acanthaceae). Araújo & Santos (2009) observed a strong relation between height, leaf number and gall number per individual. According to the authors, plant size is synonymous of resource availability, because the larger the plant and its structural complexity, the higher is the number of insects that it may host.

Araújo *et al*. (2006) showed that plant architecture has also positively influenced richness, abundance and survival of galls induced on *Baccharis pseudomyriocephala* Teodoro (Asteraceae) shrubs. Similar results were found for other species of the *Baccharis* (Espírito-Santo *et al*. 2007) genus. Vrcibradic *et al*. (2000) affirm as a strategy of galling insect reproduction, the oviposition on plants with greater number of leaves. These authors also mention that such strategy lowers the risk of attacks by natural enemies and parasitoids. Plants with greater number of leaves offer more oviposition site availability and as a consequence, suffer with more galling attacks (Collevatti & Sperber 1997).

Despite the coherence of the plant architecture, its contrary results deserve consideration. In our opinion, architectural parameters can be masked by the quantity of undifferentiated tissue available. Architecturally more complex plants do not necessarily offer greater quantity of undifferentiated tissue if not during regrowth period, so that the unavailability of theses tissues may standardize the response of architecturally distinct plants.

In general, galling insects seems to have its distribution affected by the nutritional and physiological conditions of its host plants, which varies according to seasonality and phenology. We believe that these issues should be considered in future studies regarding the subject (Araújo & Santos 2008).

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Table 1: Relation between architectural variations and gall abundance on both plant species studied in Maricá Restinga, RJ, Brazil.

|  |  |  |  |
| --- | --- | --- | --- |
| Variance |  *Clusia lanceolata* |  | *Monteverdia obtusifolia* |
|  estimate | standard error | z  | p |  estimate | standard error | z  | p |
| Intercept | -0.9349 | 0.3057 | -3.058 | 0.0022 | -19.716 | 0.6451 | -3.057 | 0.0022 |
| Height | -0.0216 | 0.134 | -0.16 | 0.8714 | 0.3776 | 0.2645 | 1.427 | 0.1534 |
| Intercept | -12.007 | 0.2814 | -4.266 | 0.0001 | -20.080 | 0.6731 | -2.983 | 0.0028 |
| 2°Nível | 0.0588 | 0.0682 | 0.862 | 0.389 | 0.2425 | 0.1713 | 1.416 | 0.1568 |
| Intercept | -10.628 | 0.1928 | -5.513 | 0.0003 | -11.059 | 0.4101 | -2.696 | 0.007 |
| Treetop | 0.1565 | 0.2721 | 0.575 | 0.565 | 0.0898 | 0.6289 | 0.143 | 0.8864 |

Figure 1: (a) Maricá municipality, Rio de Janeiro, Southeast Brazil. (b) Area of study: Área Protegida Ambiental de Maricá.

Figure 2: Plants and galling insect species. (a) *Clusia lanceolata* Cambess., (b) *Clusiamyia nitida* Maia, 1996, (c) *Monteverdia obtusifolia* (Mart.) Biral, (d) *Mayteniella distincta* Maia, 2001.