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## First Report of Insect Galls on *Ficus microcarpa* in Penghu Islands, Taiwan

YOU-TING HSIEH<sup>1</sup>, SHENG-FENG LIN<sup>2</sup>, YI-CHANG LIAO<sup>3</sup>

<sup>1</sup> Institute of Ecology and Evolutionary Biology, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei 106319, Taiwan. E-mail: hsieh.you.ting@gmail.com

<sup>2</sup> Department of Entomology, National Chung Hsing University, No. 145 Xingda Rd., Taichung 402, Taiwan. E-mail: sflin654@gmail.com

<sup>3</sup> Department of Entomology, University of California, Riverside, 900 University Ave, Riverside, CA 92521, USA. E-mail: ycliaopsyllids@gmail.com

**Abstract.** The morphology of insect galls often has a species-specific relation to gall-inducers. Therefore, using gall morphotypes as a surrogate of insect species, researchers can preliminarily investigate the gall-inducing insect fauna of an area. The Penghu Islands are the largest offshore islands of Taiwan, but the gall-inducing insect fauna is poorly known. In this study, we selected the widespread Chinese banyan (*Ficus microcarpa* L.) as the target of our faunistic survey focused on gall-inducing insects. We collected insect galls on *F. microcarpa* in Magong island, Baisha island and Xiyu island from September 2020 to February 2021. A total of 4 gall morphotypes were newly recorded in the islands. These gall morphotypes were induced by *Horidiplosis* sp. and an unidentified gall midge (Diptera: Cecidomyiidae, 2 morphotypes), *Macrohomotoma gladiata* Kuwayama (Hemiptera: Carsidaridae), and *Gynaikothrips* sp. (Thysanoptera: Phlaeothripidae, 1 morphotype). We infer and discuss the potential taxonomic position of each gall-inducing insect based on given specimens and gall morphotypes. Gall-inducing insects on *F. microcarpa* in Penghu Islands might naturally disperse from neighboring regions, such as mainland China or Taiwan Island, but there is a possibility that gall-inducing insects were introduced from the southern part of Taiwan Island due to the import of nursery trees for the afforestation project in the 1910s. Further molecular work could help clarify the origin of the gall-inducing insects on *F. microcarpa* in Penghu Islands.

**Key words:** Cecidomyiidae, Carsidaridae, *Gynaikothrips*, native plant

### Introduction

Gall-inducing insects are one of the most specialized types of herbivores that induce galls, abnormal growth, on the host plant to gain nourishment, shelter and protection (Price et al., 1987; Stone & Schönrogge, 2003; Shorthouse et al., 2005). Most gall-inducing insects dwell inside galls before reaching adult stage (Mani, 1992). Although gall-inducing insects have the conspicuous habit, their species classification is often deficient, especially in tropical regions (Espírito-Santo & Fernandes, 2007). The lifetime of adults is relatively short, and therefore adult specimens are not readily available. This situation makes taxonomic study of gall-inducing insects particularly difficult. However, galls are immobile, relatively noticeable in the wild, and exist after adults' emergence. In addition, most gall-inducing insects are highly specific to their host plants and plant organs (Dreger-Jauffret & Shorthouse, 1992). Species classification of gall-inducing insects can be tentatively defined into gall morphotypes according to the combination of their host plants, host organs, and the external morphology (Fernandes & Price, 1988; Price et al., 1998; Carneiro et al., 2009). Therefore, gall morphotypes have been considered as species units in ecological studies (Yukawa, 2018).

The faunistic studies of Taiwanese gall-inducing insects started in 1995 (Yang & Tung, 1998; Yang et al., 2000a, b; Tung et al., 2006; Yang et al., 2006; Pan et al., 2018). These studies used gall morphotypes to estimate the species diversity of gall-inducing insects. Although the above-mentioned studies included offshore islands, the gall-inducing insect diversity might be underestimated due to the lack of a comprehensive investigation. The Penghu Islands, consisting of 90 small islands with a total land area of ~127 km<sup>2</sup>, are situated away from the west coast of Chiayi County (western Taiwan Island) about 50 km. The spatial range of the Penghu Islands spans 23°12'–23°47'N and 119°19'–119°43'E. The Penghu Islands are volcanic islands, and are the largest offshore islands of Taiwan. In Penghu Islands, Magong Island is the largest island (67.14 km<sup>2</sup>), followed by Hsiyu (18.71 km<sup>2</sup>) and Baisha (13.88 km<sup>2</sup>). Although it is situated in a subtropical monsoon climate and surrounded by the ocean, the average annual rainfall is about 1000 mm due to the mountainless topography (Chen, 1953). The strong sea breeze profoundly influences the vegetation in the winter (Tsai, 2009). Furthermore, the islands have a long colonial history (Taisaku, 2020), which made the landscape treeless. Despite its

large area, there were only two gall-inducing insects recorded in Penghu Islands. Yang et al. (2004) recorded an invasive gall wasp, *Quadrastichus erythrinae* Kim, inducing galls on *Erythrina variegata* (Fabaceae), and Hong (1997: Figs 160–161) accidentally recorded an image of galls induced on the flower head of *Pluchea indica* (Asteraceae) with no further description on gall morphology or the gall inducer.

*Ficus* L. (Moraceae), fig tree, is a pantropical and the most diverse genus of woody plants, comprising 735 known species worldwide (Berg et al., 2005). Fig trees have been well-known among biologists for their obligate mutualism with pollinating wasps which induce gall tissue inside syconia (Bain et al., 2015). Besides, fig trees also harbor a large amount of herbivores (Basset et al., 1997; Basset & Novotny, 1999; Yang et al., 2008; Mifsud et al., 2012), including numerous gall-inducing species (Docters van Leeuwen-Reijnvaan & Docters van Leeuwen, 1926). Among fig trees, *F. microcarpa* is widespread in East Asia and distributes in low altitude regions in Taiwan (Liao, 1996). *Ficus microcarpa* presently forms forest in several relatively high inland regions and along the coastline (Hsieh, personal observation). Although once introduced for the afforestation project in the period of Japanese rule, *F. microcarpa* is probably a native species in Penghu Islands because of evidence from early Japanese plant surveys (Tashiro, 1895a, b), and the presence of a huge standing tree which is at least 300 years old (Chen, 1953).

To generate faunistic information of gall-inducing insects on *F. microcarpa* in Penghu Islands, the first author conducted 11 field surveys from September, 2020 to February, 2021. In this paper, we report insect galls that were newly recorded in these surveys.

## Materials and methods

Insect galls on *F. microcarpa* were collected from Magong Island, Baisha Island and Xiyu Island from September 2020 to February 2021. The host plant, dates of collecting, locations, gall-bearing plant organs, and gall external morphology were recorded as collecting information. Plant branches with galls were cut, placed in polyethylene bags and transported to the laboratory. Samples of some galls were dissected and the developmental stages of the gall inducer was documented. Full-grown larvae and pupae were taken and preserved in 70% ethanol for further morphological examination. Samples of galls from the same collecting event at each site were identified by a lot number based on the date of collection where “TR20201024-YTH01” refers to the name of the database (TR for collecting database), the date of collecting (20201024 for 24 October, 2020), the name of collector (YTH for the first author), and the sequential number of lot (01 for the first collecting lot on 24 October, 2020). For rearing of the gall inducer, each sample of galls was transferred to a new polyethylene bag (350 by 250 mm) in the laboratory as a rearing lot, containing wet tissue paper to keep the moisture. Rearing bags were kept at room temperature, checked once a day to obtain adults of gall inducers. Once adults emerged, they were picked out with ethanol-moistened tweezers and transferred to a vial of 70% ethanol. Rearing lots follow a similar system as collecting lots, where “Rr20201024-YTH01” refers to the name of the database (Rr for rearing database), the beginning date of rearing (20201024 for 24 October, 2020), the name of rearer (YTH for the first author), and the sequential number of lot (01 for the first rearing lot on 24 October, 2020). A rearing lot number should always follow a collecting lot number to indicate the information of collection. All wild photos were recorded with a digital camera (Nikon Coolpix P7700), and archived following lot numbers.

Galls were classified into morphotypes using the host plant species, organ of occurrence, and the external morphology (shape, color, pubescence and size). For gall shape description, we followed the nomenclature of the insect gall morphospecies standardized and proposed by Isaías et al. (2013) and Isaías et al. (2014), then compared descriptions in the literature, and only created new shapes when there was no similar adjective term. Gall inducers were identified using the insect gall literature from East Asia (e.g., Yukawa & Masuda, 1996; Chen & Qiao, 2012; Tung et al., 2018). In the results reported here, galls were arranged according to the order of plant families and the taxon of the host plant. Entries for each gall were arranged in the following order: (1) galled organ and the taxon of the gall-inducing insect, if identifiable, (2) Chinese common name of the gall inducer, (3) gall shape description, (4) known distribution records with literature citation, if any, (5) voucher specimen data, and (6) Remarks, if any. For the specimen data, a double slash (//) was used to denote the line breaks on labels, while supplementary data (which may not be written on the labels, themselves) were presented in square brackets ([ ]). Voucher specimens were deposited in NCHU (National Chung Hsing University, Taichung, Taiwan) and YTHc (You-Ting Hsieh, private collection, Pingtung, Taiwan).

## Results

### New insect galls found on the Penghu Islands

#### MORACEAE

#### *Ficus microcarpa* L. f.

1. Leaf gall induced by *Horidiplosis* sp. (Diptera: Cecidomyiidae) (Figs 1A, 2A)

**Chinese common name:** 榕葉癭蚋

**Gall shape:** Lenticular.

**Known distribution records:** Penghu Islands, Taiwan (present study)

**Voucher specimen data:** 5♀♀ (Rr20201017-01 from TR20201017-01): collected from Aimen Beach (隘門沙灘), Penghu Co., Taiwan, 17-X-2020, leg. Y. T. Hsieh, emerged between 30-X-2020–31-X-2020 (NCHU); 1♂1♀ (Rr20201024-04 from TR20201024-01): collected from Aimen Beach (隘門沙灘), Penghu Co., Taiwan, 24-X-2020, leg. Y. T. Hsieh, emerged on 08-XI-2020 (NCHU); 10♀♀ (Rr20201115-YTH02 from TR20201115-YTH01): collected from Magoon (馬公), Penghu Co., Taiwan, 15-XI-2020, leg. Y. T. Hsieh, emerged between 02-XII-2020–11-XII-2020 (NCHU).

**Remarks:** The gall morphotype is similar to galls induced by *H. ficifolii* Harris which was described based on specimens reared from another common glasshouse fig tree, *Ficus benjamina* L. (Harris & Goffau, 2003), but further found to infect *F. microcarpa* (Steck & Krueger, 2008). *Horidiplosis ficifolii* was first detected on fig trees imported from Southeastern Asia (Taiwan, Japan, and China) to the Netherlands and the UK, and later reported in Italy (Suma et al., 2007), USA (Florida) (Steck & Krueger, 2008), and Czech Republic (Beránek & Šafránková, 2010). Further examination on specimens of this *Horidiplosis* species is needed to clarify its species identity.

Besides, although *H. ficifolii* has been intercepted in Europe on leaves of *Ficus benjamina* L. exported from Taiwan (Harris & Goffau, 2003), whether the species occurs in main Taiwan is still questionable due to the imprecise location of those original samples.

2. Flower gall induced by an unidentified cecidomyiid (Diptera: Cecidomyiidae) (Figs 1B, 2B)

**Chinese common name:** 榕果癭蚋

**Gall shape:** Crown-like ridge outside the syconia (cf. Yafuso et al., 2013).

**Known distribution records:** Penghu Islands, Taiwan (present study)

**Voucher specimen data:** Galls (TR20201024-01): collected from Aimen Beach (隘門沙灘), Penghu Co., Taiwan, 24-X-2020, leg. Y. T. Hsieh (NCHU); 10♂♂17♀♀ (Rr20201024-01, TR20201024-01): collected from Aimen Beach (隘門沙灘), Penghu Co., Taiwan, 24-X-2020, leg. Y. T. Hsieh, emerged between 24-X-2020–26-X-2020 (NCHU).

**Remarks:** This gall morphotype was induced in the syconia, causing abnormal growth outside. Similar morphotypes were recorded to be induced by *Ficiomyia perarticulata* Felt on *Ficus citriflora* Miller in Florida, USA (Roskam & Nadel, 1990), by unidentified species on *Ficus benjamina* L. in Xishuangbanna, China (Bai et al., 2008; Miao et al., 2011), and by other unidentified species on *Ficus microcarpa* L. in Okinawa and Amami, Japan (Yafuso et al., 2013).

3. Shoot gall induced by *Macrohormotoma gladiata* Kuwayama (Hemiptera: Carsidaridae) (Figs 1C, 2C)

**Chinese common name:** 高背木蝨

**Gall shape:** Rosette.

**Known distribution records:** China, Japan (Ryukyu island), Malaysia, Taiwan (including Penghu Islands, present study); introduced into Algeria, Morocco, Tunisia, Italy, Montenegro, Spain, USA (California, Hawaii) (Yang, 1984; Li, 2011; Pedata et al., 2012; Rung, 2016; Radonjić & Hrnčić, 2017; Burckhardt et al., 2018; Afechtal et al., 2021; Harbi et al., 2021).

**Voucher specimen data:** 5♂♂1♀, 9 larvae (Rr20201024-02 from TR20201024-01): collected from Aimen Beach (隘門沙灘), Penghu Co., Taiwan, 24-X-2020, leg. Y. T. Hsieh, emerged between 25-X-2020–28-X-2020 (NCHU); 2♀♀, 7 larvae (Rr20201121-YTH04 from TR20201121-YTH03): collected from Waian (外垵), Penghu Co., Taiwan, 21-XI-2020, leg. Y. T. Hsieh, emerged between 22-XI-2020–23-XI-2020 (NCHU).

**Remarks:** Some galls were only recorded with photos at Magong Ancient Castle (媽宮古城), Penghu Co., Taiwan (on 21-XI-2020, leg. Y. T. Hsieh, Rr20201115-YTH03 from TR20201115-YTH03). This species originated in the oriental region and was introduced to Europe, North America and northern Africa over the past ten years. Its host plant has been widely planted as ornamental plants and eggs hide in new leaf buds that make them quite cryptic in the early stage. Therefore, *M. gladiata* may be easily transferred artificially via its host plant. In the native region, *M. gladiata* is generally not considered as a serious pest. However, in an invasive region, the infestation of *M. gladiata* on *F. microcarpa* would be much more severe and needs chemical control.

4. Shoot gall induced by *Gynaikothrips* sp. (Thysanoptera: Phlaeothripidae) (Figs 1D, 2D)

**Chinese common name:** 榕薊馬、榕管薊馬、榕癭薊馬

**Gall shape:** Marginal roll.

**Known distribution records:** The two candidate species were introduced from Southeast Asia, and spread throughout the tropics and subtropics where the host plant cultivated (Mound et al., 1995; Held et al., 2005).

**Voucher specimen data:** Galls and 2 adults (Rr20201115-YTH04 from TR20201115-YTH01): collected from Magoon (馬公), Penghu Co., Taiwan, 15-XI-2020, leg. Y. T. Hsieh (YTHc); Galls and 1 adult (Rr20201115-YTH05 from TR20201115-YTH03): collected from Magong Ancient Castle (媽宮古城), Penghu Co., Taiwan, 15-XI-2020, leg. Y. T. Hsieh (YTHc); Galls and 2 adults (Rr20201121-YTH03 from TR20201121-YTH03): collected from Waian (外垵), Penghu Co., Taiwan, 21-XI-2020, leg. Y. T. Hsieh (YTHc).

**Remarks:** Two congeneric species of the genus *Gynaikothrips*, *G. ficorum* (Marchel) and *G. uzeli* Zimmermann, induce leaf rolling galls on *Ficus* spp. and have been reported in main Taiwan (Mound et al., 1995; Wang & Lin, 2020). The distinction of these two species is debated because of inconspicuous morphological difference (Mound et al., 1995; Mound & Marullo, 1996; Wang & Lin, 2020; Mound & Tree, 2021), but two names are still retained and followed here for the convenience of future studies. Though the two species often coexist in the same gall on both *F. microcarpa* and *F. benjamina* L. (Tree et al., 2015), host specificity experiments showed that *G. ficorum* could only initiate the formation of galls on *F. microcarpa* (Tree et al., 2015; Arthurs et al., 2016). However, our observation in Penghu was somehow not consistent with Tree et al. (2015) and Arthurs et al. (2016). During our surveys, *G. ficorum* was only presented in one of our collections with the coexistence of *G. uzeli* (Rr20201115-YTH04 from TR20201115-YTH01), while *G. uzeli* presents alone in all other collections. Tree & Walter (2009) found adults of *Gynaikothrips* species could move between galls freely, therefore non-inducer species might occasionally enter galls of other gall-inducing species, even after the leaving of gall inducers. Despite studies in the literature, we highly suggest further careful observation about the gall-inducing habit in the wild is needed to clarify the true gall inducer of this morphotype.

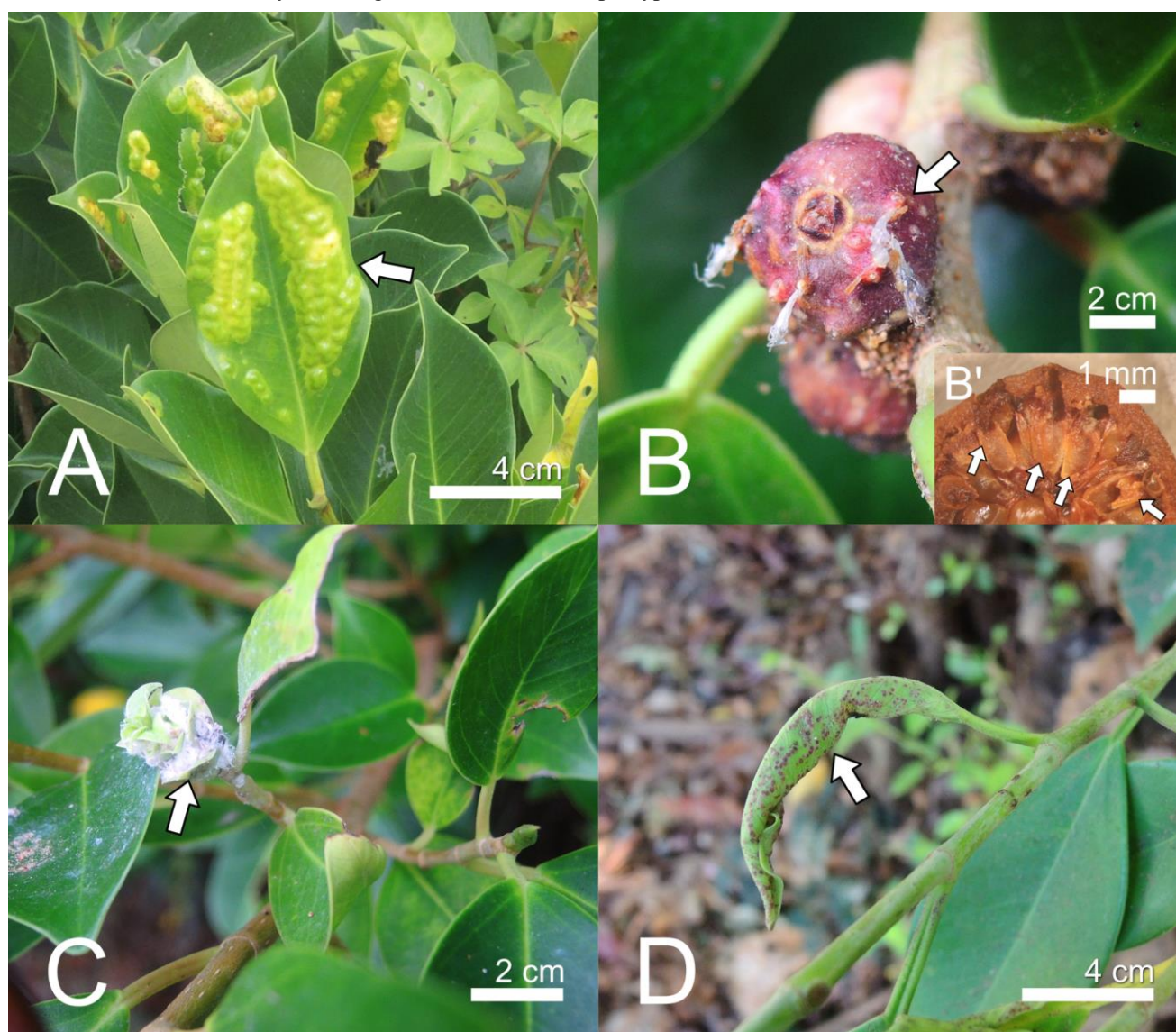


Figure 1. Gall morphotypes of *Ficus microcarpa* in Penghu Islands. A, lenticular galls on leaves; B, crown-like ridges outside the syconia; B', flower galls inside the syconia; C, a rosette gall on a shoot; D, a marginal roll gall on a leaf. Arrows indicate the locations of galls.

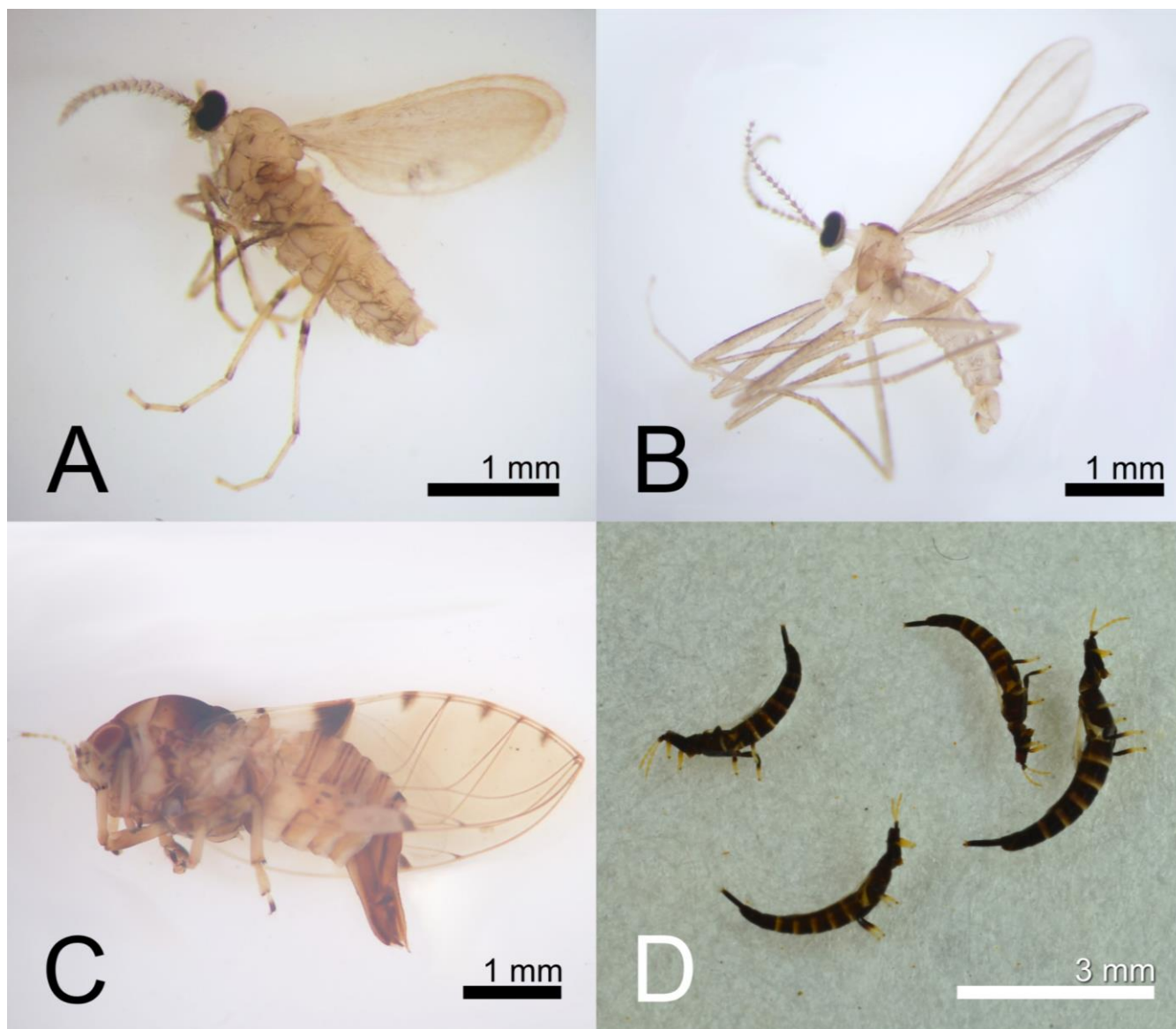


Figure 2. Habitus of the gall inducer of each gall morphotypes on *Ficus microcarpa* in Penghu Islands. A, Male *Horidiplosis* sp.; B, Male Cecidomyiidae unid. sp.; C, Female *Macrohomotoma gladiata*; D, An adult and larvae of *Gynaikothrips uzeli*.

### Discussion

*Ficus microcarpa* has been reported as a host of several gall-inducing insects, e.g. cecidomyiids (Steck & Krueger, 2008; Yafuso et al., 2013), psyllids (Hollis & Broomfield, 1989), and thrips (Mound et al., 1995). In Penghu Islands, the gall-inducing insect fauna on *F. microcarpa* hasn't been recorded before. In this study, a total of 4 gall morphotypes were newly recorded in the islands. More than that, since *F. microcarpa* in Penghu Islands was able to regenerate (Hsieh, personal observation), thus it should host its mutual pollinating wasp to be pollinated. *Eupristina verticillata* Waterston, the mainly pollinating wasp of *F. microcarpa* which inducing flower galls in the syconia (Chen et al., 1999; Bain et al., 2015), should logically occur in the Islands. The gall-inducing insects on *F. microcarpa* in the Penghu Islands tentatively totals 5 species. It should be noted that our surveys didn't cover the whole growing season, e.g. in spring and summer. Further investigation is suggested to be conducted in these seasons.

Penghu Islands are of volcanic origin, and the flora and fauna of islands were deduced to originate from neighboring regions (Carlquist, 1974). The gall-inducing habit makes the host-shifting event less frequent compared to other non-gall-inducing herbivores, because gall-inducing insects are tightly associated with their host plants (Yukawa & Uechi, 1999). This suggests that gall-inducing insects might colonize the islands with the introduction of their host plants. Wang et al. (2007) showed that the flora of Penghu Islands was most similar to Taiwan island and mainland China, which implies the two possible sources of its gall-inducing insect fauna. In this study, a total of 4 gall-inducing insects were found in Penghu Islands. Two of them, *M. gladiata* and *Gynaikothrips* sp., occur in both mainland China (Mound et al., 1995; Held et al., 2005; Li, 2011) and Taiwan Island (Tung et al., 2018), although it is still unknown whether the *Horidiplosis* fig cecidomyiid (Fig. 2A) and the unidentified species (Fig. 2B) are also distributed in both regions. From another aspect, gall-inducing insects are highly likely to be introduced and successfully

establish due to extensive introduction of their host plants from native regions (Csóka et al., 2017). It was recorded that the colonial government once exported nursery trees of *F. microcarpa* from Hengchun (恆春) township of southern Taiwan to Penghu in 1911 for the afforestation project (Taisaku, 2020). The gall-inducing insects on *F. microcarpa* in Penghu Islands might accidentally be introduced due to the import of nursery trees. This “Introduced from Taiwan Island by importing nursery trees” hypothesis could be tested by further works using molecular phylogenetic methods and DNA haplotypes.

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## 臺灣澎湖群島產正榕之蟲癭的首次報導

謝侑廷<sup>1</sup>、林聖豐<sup>2</sup>、廖一璋<sup>3</sup>

<sup>1</sup>國立臺灣大學生態學與演化生物學研究所 106319 臺北市羅斯福路四段 1 號

<sup>2</sup>國立中興大學昆蟲學系 40227 臺中市南區興大路 145 號

<sup>3</sup>加利福尼亞大學河濱分校 昆蟲學系 92521 美國加州大學大道 900 號

**摘要:** 蟲癭型式多數與其造癭者具有種間對應的關係，因此透過蟲癭形態種的調查，研究者可以初步判斷一地區的造癭昆蟲相。澎湖群島是臺灣最大的離島群，然而目前並不瞭解島上的造癭昆蟲相。在本研究中，我們選擇於澎湖群島廣布的正榕 (*Ficus microcarpa* L.) 作為造癭昆蟲相調查的目標。我們於西元 2020 年 9 月至西元 2021 年 2 月，針對馬公島、白沙島及西嶼島生長之正榕，進行蟲癭的採集。研究結果共新增 4 種蟲癭形態種於澎湖地區的紀錄，造癭昆蟲類群包含癭蚋 (雙翅目：癭蚋科) 2 形態種 (*Horidiplosis* sp. 及一未鑑定物種)、高背木蠹 (*Macrohomotoma gladiata* Kuwayama) (半翅目：錦葵木蠹科)，及榕母管蓊馬屬 (*Gynaikothrips* sp.) (縷翅目：管蓊馬科) 1 形態種。我們就現有標本討論了各形態種的分類地位。澎湖群島產正榕上的造癭昆蟲可能由鄰近區域 (如中國及臺灣) 天然擴散而來，但亦可能隨著 1910 年代因為造林目的而輸入的樹苗，自臺灣南部引入。進一步透過分子生物學研究，將可協助釐清澎湖群島產正榕上造癭昆蟲的來源。

**關鍵詞:** 癭蚋科、錦葵木蠹科、母管蓊馬屬、原生植物