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The Diversity of Gall-Inducing Plants and Insect-Induced Galls in Guandaushi Forest Ecosystem of Central Taiwan

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ABSTRACT: Guandaushi forest ecosystem is a long-term ecological research (LTER) site in central Taiwan. There are totally 326 vascular plant species in which 27 species belonging to 16 families bear insect-induced galls. Among these host plants, 8 species are vines and 19 species are woody trees. Six species of Lauraceae and four species of Fagaceae have galls. Forty-five morphologically different insect-induced galls were found. About 60% are prosoplasmatic galls based on Küster classification; 50% are covering galls based on Dreger-Jauffret and Shorthouse classification. The gall makers of Cecidomyiidae (Diptera) induced 9 different galls.

KEY WORDS: Gall-inducing plants, Insect-induced galls, Guandaushi.

INTRODUCTION

Insect-induced gall is an abnormal growth on some part of plant due to the activity of insects. In medieval Europe, plant galls were used as medicine and dyestuff and were the subjects of superstition and folklore (Williams, 1994). In Chinese, people have used the nutgalls induced by aphids on the genus *Rhus* to extract tannic acids for medical and industrial uses since 2000 years ago. There were only simple descriptions about some insect galls of Homoptera in early Taiwan (Takahashi, 1933, 1936). In current years, there have been some informations about gall inventories (Yang, 1996; Tung, 1997) and some studies about insect galls of specific plants (Yang *et al.*, 1996; Yang *et al.*, 1999). The study on fig wasps (Chen, 1994; Tseng, 1999) and development of insect gall (Liang *et al.*, 1999) were also proceeded. The gall-induced insects are highly host specific and also organ specific. There are two main classification systems of galls. One is by Küster (1911) and the other one is by Dreger-Jauffret and Shorthouse (1992). Küster classified galls depending on the degree of differentiation of gall tissue. The classification of Dreger-Jauffret and Shorthouse was based on the modes of gall formation. The biodiversity and potential uses of insect galls should be studied further in Taiwan. We inventoried the diversity of gall-inducing plants and insect-induced galls in Guandaushi forest ecosystem of central Taiwan, and then grouped these galls based on the both classification systems.

MATERIALS AND METHODS

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The Guandaushi forest in central Taiwan is a long-term ecological research (LTER) site. The insect-induced galls in this forest ecosystem were investigated from September 1994 to March 1998. Four types of understory selected for study are virgin hardwoods, artificial plantation, secondary hardwood, and the burned site. For insect gall investigation, a random search was made along the trail at each stand and eight 10m line transects were placed along the walkway at each stand. Dissected galls were observed under the stereo microscope and SEM to classify the galls. The specimens of gall-inducing plants were kept at herbarium and the specimens of gall makers were preserved in 70% alcohol at room temperature.

RESULTS AND DISCUSSION

In Guandaushi forest, there are 326 vascular plant species in which 27 species belonging to 16 families bear insect-induced galls (Table 1). Among these host plants species, 8 species are vines and 19 species are woody trees. Forty-five morphologically different insect-induced galls were identified. The main groups of gall-inducing plants are members of the families Lauraceae and Fagaceae. Six species of Lauraceae and four species of Fagaceae have galls (Table 1). There is high diversity of galls in Lauraceae, especially the genus *Machilus*, in Guandaushi forest (Yang *et al*., 1996, 1999). Kinds of galls collected from the 6 species of Lauraceae are shown in Table 1. All plant organs, including leaves, stems, twigs and buds, are subject to galling. For all the galls in Guandaushi forest, 44.4 % were on the leaf, 42.3% on the stem, and 13.3% on the bud (Table 2). The common host plants of galls vary with geographical regions (Mani, 1964; Yukawa & Masuda, 1996). Most gall-inducing insects are highly host and organ specific (Derger-Jauffret & Shorthouse, 1992). Mani (1964) indicated that most insects prefer leaves to induce galls.

Galls are induced by a wide variety of organisms, but this study in Guandaushi forest is restricted to the insect-induced galls. Among the 45 kinds of insect galls collected in Guandaushi forest, the gall makers of 19 types were recognized. They belong to 5 orders and 6 families (Table 3). The Cecidomyiidae (Diptera) induced 9 different galls that were mostly found on plants of Lauraceae. Psyllidae (Homoptera) induced 4 different galls. The gall-induced insects of Cecidomyiidae and Cynipidae mostly induced the covering galls and prosoplasmatic galls on leaves. The Psyllidae induced the pit, blister and bud galls. The Hormaphidae induced the bud galls. The Curculionidae and Lyonetiidae formed the mark galls. The family Cecidomyiidae is ancient, but plant feeding probably evolved during the period of green plant radiation in the late Cretaceous. Cecidomyiidae presumably were preadapted for plant feeding and gall-inducing in an early period of angiosperm radiation (Roskam, 1992). In Guandaushi forest, the family Cecidomyiidae induced the most galls on host plants, especially in Lauraceae. About 13,000 insects species of gall makers have been recorded, which represents about 2% of the total species of insects (Buhr, 1965). Harris (1994) mentioned that the gall makers of Cecidomyiidae always induce structurally complex and highly differentiated gall.

Based on the Küster classification (1911), the percentage of prosoplasmatic galls in Guandaushi forest was 57.78%; and that of kataplasmatic galls was 42.22%. Based on the classification of Dreger-Jauffret and Shorthouse (1992), 6 types of galls were recognized (Table 4). The occurring frequency, from the most to the least, was covering gall (51.11%), mark gall (26.67%), bud gall (13.33%), pit gall (4.45%), blister gall (2.22%) and pitch gall (2.22%) (Table 4). The classification of Küster was based on the degree of differentiation of galls, and that of Dreger-Jauffret and Shorthouse was based on the modes of gall formation.

Table 1. The host plants of insect galls in Guandaushi forest.

Family	Plant species	Kinds of gall
Plagiogyriaceae	*Plagiogyria dunnii*	1
Fagaceae	*Castanopsis eyrei*	1
	Castanopsis fargesii	2
	Castanopsis stipitata	1
	Pasania konishii	2
Proteaceae	*Helicia formosana*	1
	Helicia rengetiensis	2
Illiciaceae	*Illicium arborescens*	1
Lauraceae	*Cinnamomum osmophloeum*	1
	Cinnamomum subavenium	5
	Litsea acuminata	3
	Machilus thunbergii	3
	Machilus zuihoensis var. *zuihoensis*	5
	Neolitsea variabillima	2
Lardizabalaceae	*Akebia longeracemosa*	2
Theaceae	*Ternstroemia gymnanthera*	1
Leguminosae	*Pueraria montana*	2
Daphniphyllaceae	*Daphniphyllum pentandrum* var. *pentandrum*	1
Aquifoliaceae	*Ilex lonicerifolia* var. *lonicerifolia*	1
Vitaceae	*Ampelopsis cantoniensis*	1
	Cayratia japonica	1
Elaeocarpaceae	*Elaeocarpus japonicus*	1
Myrtaceae	*Syzygium buxifolium*	1
Myrsinaceae	*Embelia oblongifolia*	1
	Maesa tenera	1
Styracaceae	*Styrax formosana* var. *formosana*	1
Scrophulariaceae	*Torenia concolor* var. *formosana*	1
Total	27	45

Table 2. The percentages of plant organs galled by insects in Guandaushi forest.

Plant organ		Kinds of gall	Percentage
Leaf	blade	15	33.33
	margin	1	2.22
	midrib	4	8.89
Bud	bud	6	13.33
Stem	node	2	4.45
	internode	17	37.78
	Total	45	100.00

Table 3. The kinds of gall insects and the types of galls in Guandaushi forest.

Gall-inducing insect		Kinds of gall	Types of gall
Order	Family		
Diptera	Cecidomyiidae	9	mark, covering; prosoplasmatic and kataplasmatic galls
Hymenoptera	Cynipidae	2	covering; prosoplasmatic galls
Homoptera	Psyllidae	4	pit, blister, bud; prosoplasmatic and kataplasmatic galls
	Hormaphidae	1	bud; prosoplasmatic galls
Coleoptera	Curculionidae	2	mark; kataplasmatic galls
Lepidoptera	Lyonetiidae	1	mark; kataplasmatic galls
Total 5	6	19	

Table 4. The types of galls in Guandaushi forest based on two classifications systems.

Classification system	Kinds of gall	Percentage
Dreger-Jauffret and Shorthouse (1992)		
pit gall	2	4.45
blister gall	1	2.22
pitch gall	1	2.22
bud gall	6	13.33
mark gall	12	26.67
covering gall	23	51.11
Total	45	100.00
Küster (1911)		
kataplasmatic gall	19	42.22
prosoplasmatic gall	26	57.78
Total	45	100.00

Synthesizing both classifications systems, we grouped and described the 45 morphologically different insect-induced galls collected from the Guandaushi forest into several types as follows:

Pit gall (Fig. 1-A)

It results from abnormal enlargement of tissues of gall-induced plant. It is kataplasmatic gall (Fig. 1-B).

Blister gall

It is the same as pit gall. The epidermis splits to form the blister. It is also kataplasmatic gall.

Pouch gall

It forms the hollow bulge and remains the ostioles. It is kataplasmatic gall .

Bud gall

(1) Terminal bud is simply enlarged. It is kataplasmatic gall.

(2) Axillary bud is hollow histoid gall (Fig. 1-C). It belongs to prosoplasmatic gall (Fig. 1-D).

Mark gall (Fig. 1-E)

It arises on stem. No matter at node and internode, the larva cavities are in pith. The mark results from the modification and proliferation of surrounding tissues. It belongs to prosoplasmatic gall (Fig. 1-F).

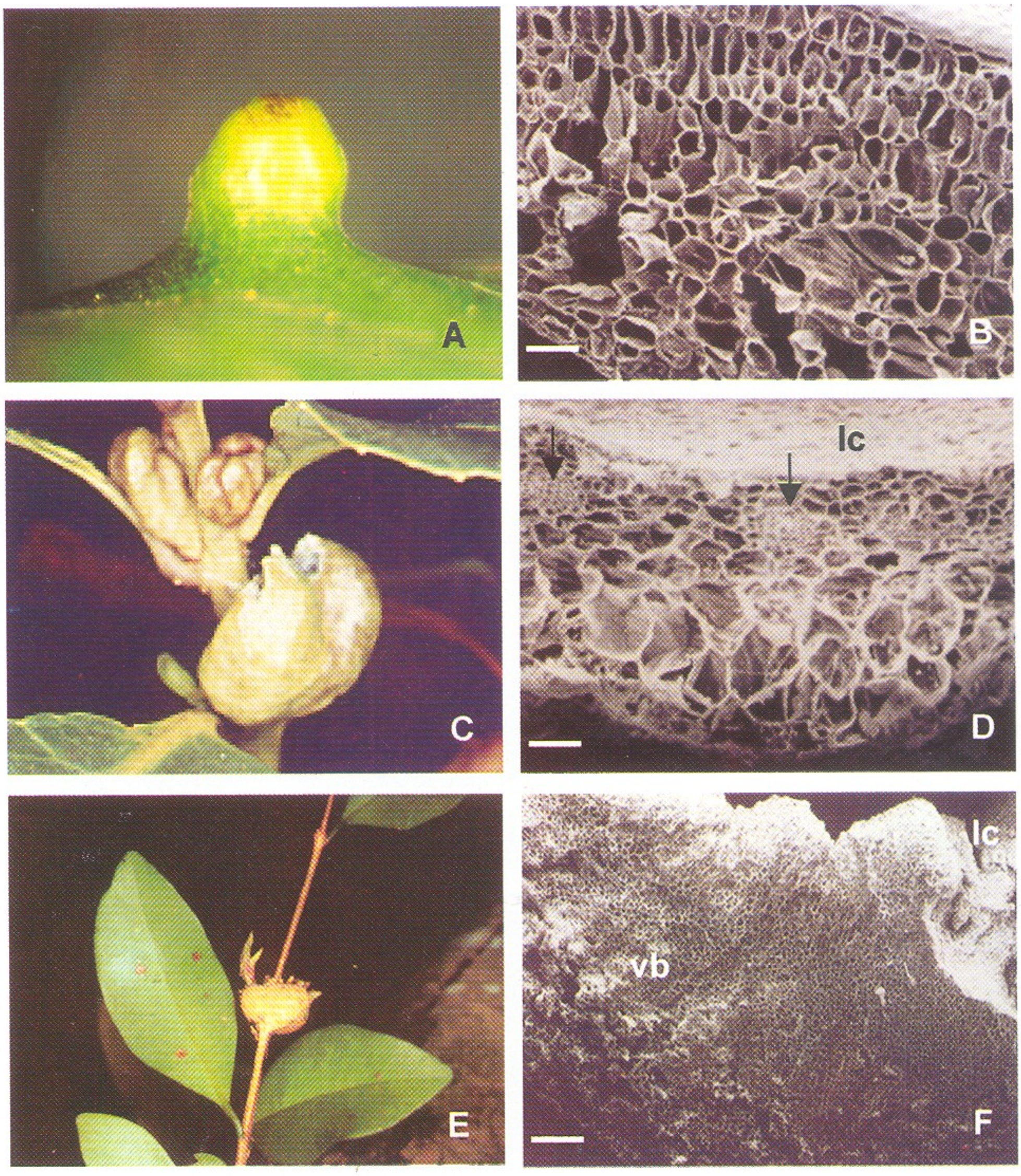

Fig. 1. A: pit gall of *Daphniphyllum pentandrum* var. *pentandrum*; B: kataplasmatic gall of *Daphniphyllum pentandrum* var. *pentandrum*, bar = 100 μm; C: axillary bud gall of *Helicia rengetiensis*; D: larva cavity (lc) and vascular bundles (arrows) of prosoplasmatic gall of *Helicia rengetiensis*, bar = 100 μm; E: mark gall of *Syzygium buxifolium*; F: larva cavity (lc) and vascular bundles (vb) of prosoplasmatic gall of *Syzygium buxifolium*, bar = 100 μm.

Covering gall (Figs. 2-A, C, E)

They arise on leaf and stem. On stem, they belong to the complex prosoplasmatic galls. On leaf, they can be divided into two groups.

(1) The tissues are lowly differentiated and no vascular cambium rearrangement. They belong to kataplasmatic galls (Fig. 2-B). Galls are easy to drop.

(2) The tissues are much more differentiated and the vascular cambiums rearrange. They belong to prosoplasmatic galls (Figs. 2-D, F).

As to the hypotheses of the adaptive nature of galls, Price *et al*. (1986) viewed and summed up into nonadaption hypothesis, plant protection hypothesis, mutual benefit hypothesis, nutrition hypothesis, microenvironment hypothesis and enemy hypothesis. Different ecological phenomena of galls may support different hypotheses. Gagné (1986) indicated that plant-feeding gall midges appear to have followed an ecological path rather

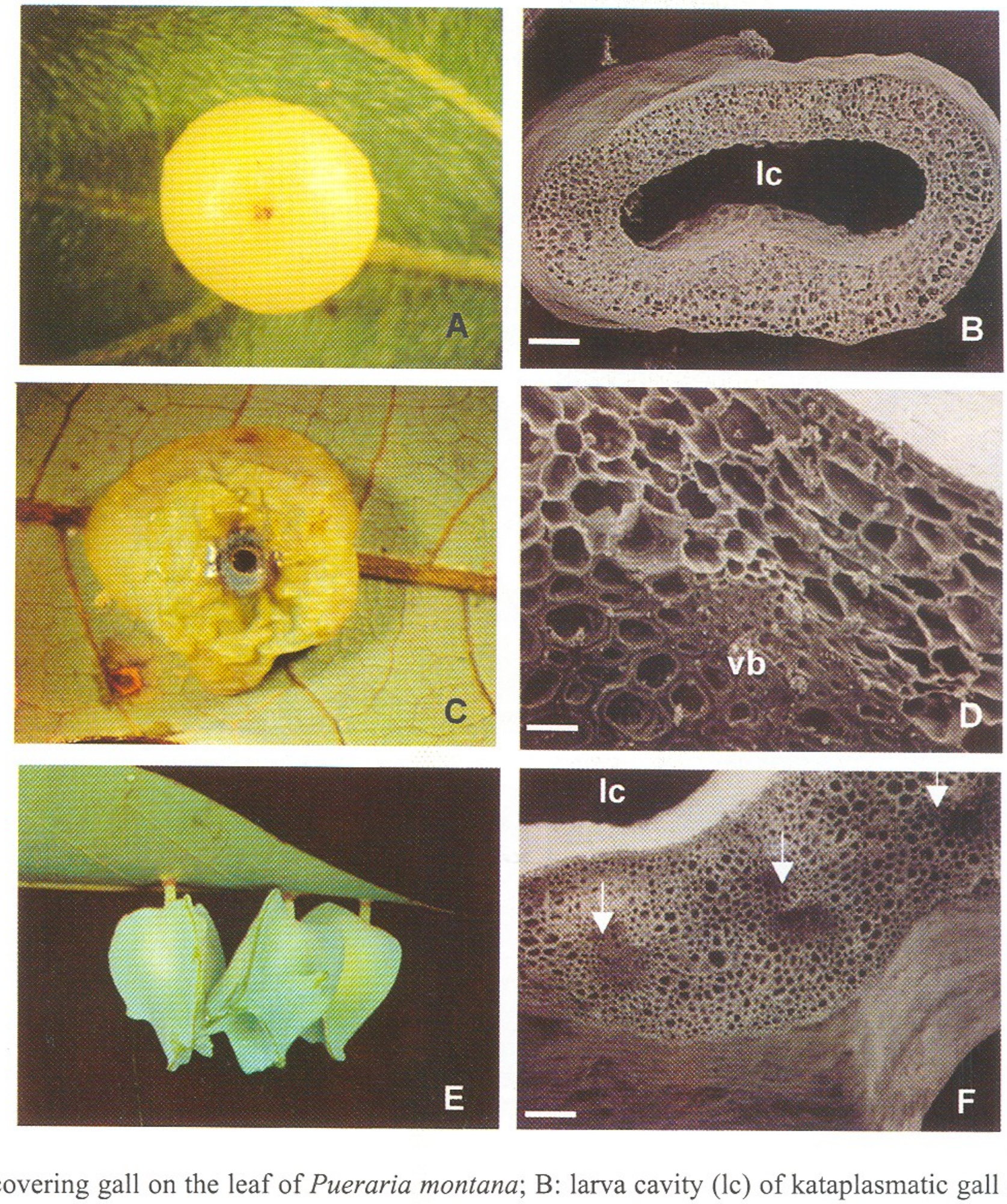

Fig. 2. A: covering gall on the leaf of *Pueraria montana*; B: larva cavity (lc) of kataplasmatic gall on the leaf of *Pueraria montana*, bar = 200 μm; C: covering gall on the leaf of *Litsea acuminata*; D: vascular bundles (vb) of prosoplasmatic gall on the leaf of *Litsea acuminata*, bar = 33.3 μm; E: covering gall on the leaf of *Machilus zuihoensis* var. *zuihoensis*; F: larva cavity (lc) and vascular bundles (arrows) of prosoplasmatic gall of *Machilus zuihoensis* var. *zuihoensis*, bar = 200 μm.

than a phylogenetic one. Perhaps the pattern of distribution of galls is related to environmental differences (Yang *et al*., 1999). If the pattern of distribution of galls can reflect the changes of environment, the galls may be tried for monitoring the long-term environmental changes of the ecosystem.

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關刀溪森林生態系之產癭植物及蟲癭多樣性

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摘　　要

關刀溪森林生態系為臺灣中部之一處長期生態研究區。在 326 種維管束植物中，有 16 科 27 種為產蟲癭植物，其中 8 種為藤本，19 種為木本植物。6 種樟科植物及 4 種殼斗科植物具有蟲癭。共紀錄到 45 類型的蟲癭，依據 Küster 分類系統，約 60%為原質性蟲癭；依據 Dreger-Jauffret 與 Shorthouse 之分類系統，50%屬於被覆型蟲癭。癭蚋科之造癭昆蟲造成 9 類型的蟲癭。

關鍵詞：產癭植物、蟲癭、關刀溪。

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