CATERPILLARS FEEDING ON *PODOCARPUS* IN TAIWAN

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ABSTRACT—External morphology and the biology of the larva and pupa of *Imma caelestis* Meyrick and *Milionia basalis* Walker from Taiwan are described. Bioassay using extracts from *Podocarpus nankoensis* leaves or frass from *M. basalis* showed that the extracts caused developmental disruption in the test insect, *Bombyx mori* L., which died in the pharate stage. Apparently the two species of caterpillars which normally feed on *Podocarpus,* have become adapted to ingesting large amounts of phytoecdysones without harmful effect. These insects may modify the phytoecdysones in some way to neutralize its molting hormone activity. The interrelationships between insects and plants is also discussed.

KEY WORDS: Phytoecdysone, Molting Hormone, *Podocarpus nankoensis, Imma caelestis, Milionia basallis, Bombyx mori*

INTRODUCTION

Podocarpus is a gymnosperm which is widely distributed in tropical and temperate regions. There are 12 genera and over 100 species in the family Podocarpaceae. Two genera and 7 species are found in Taiwan (Lu & Liao 1987; Keng, 1987).

Nakanishi et al. (1966) demonstrated that compounds isolated from *Podocarpus* were related by structure and biological activity to ecdysteroids. Ponasterone A, a phytoecdysones, was isolated from leaves of *Podocarpus,* and showed to have molting hormone activity (Hoffmeister et al., 1968; Shieh, 1982). The biological basis for some plants having evolved the ability to biosynthesize steroids with MH activity is still unknown (Morgan and Poole, 1977). However, a protective function against insect attack has been suggested.

Many insects successfuly develop and reproduce while feeding on plants that contain considerable amounts of phytoecdysones. Apparently, some species of insects have adapted to plants containing MH activity by evolving efficient methods of metabolizing and excreting phytoecdysones (Slama, 1979).

In their list of larval host plants for forest pests in Taiwan, Chang & Hung (1986) note the following species on *Podocarpus: Aonidiella aurantii* (Maskell), *A. taxus* Leonardi, *Chrysomphalus ficus* Ashmead, *Fiorana japonica* Kuwana, *F. pinicola* Maskell, *Icerya seychellarum* (Westwood), *Lepidosaphes maskelli* (Cockerell), *Pinnaspis aspidistrae* (Signoret) (all preceding Homoptera: Coccoidea), *Neophyllaphis podocarpi* Takahashi (Homoptera: Aphididae), *Homona menciana* Walker (Lepdidoptera: Tortricidae), and *Milionia basalis* Walker (Lepidoptera: Geometridae).

The larvae of two insect species, *Imma caslestis* Meyrick and *M. basalis* Walker, were found by the author, to feed on *Podocsrpus* in Taiwan. There is a paucity of information about the morphology and the biology of the larval stages of these two species. This paper describes the morphology and biology of *I. caslestis* and *M. basalis* including how these larvae adapt to feeding on plants containing MH activity.

MATERIALS AND METHODS

All insects included in this study were collected as eggs or larvae from *Podocarpus* in the field. Feeding and associated plant damage were observed and photographed in the field as well as in the laboratory. A small sample larvae in various stages of development were fixed in the boiling water and preserved in 75% ethanol for morphological

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examination. Other larvae were reared to pupal and adult stages, with some examples of each preserved for later study.

Rearing took place in transparent plastic containers containing twigs and leaves of host plant. Moisture levels were maintained with dampened paper toweling placed underneath the host plants. Specimens of terminal instar larvae and intact pupae were fixed in boiling water, and preserved in 75% ethanol. Some pupae were permitted to develop through adult eclosion in transparent containers. Genitalia were dissected, mounted on slides, and photographed with a camera attached to a dissecting microscope.

Ethyl acetate extract of the leaves of *P. nankoensis,* and of the larval frass of *M. basalis* feeding on leaves of *P. nankoensis,* were analyzed for phytoecdysteroid activity. 70 g of homogenized leaves of *P. nankoensis* and 70 g of frass were eluted in 300 ml of ethyl acetate. 7 ml of each extract were evaporated to dryness in a beaker, and then redissolved in 10 ml distilled water. This aqueous solution was spread on the surface of fresh leaves of mulberry *(Morus)* using cotton swabs, let dry, and fed to second and third instar silkworms (Lepidoptera: Bombycidae: *Bombyx mori* L.) obtained from the Taiwan Silkworm and Honey Bee Experimental Station. Control studies were done using leaves treated with an aqueous suspension derived from the drying of solvent ethyl acetate only. Effects were observed daily, and newly treated leaves supplied every two days, until pupation or death of larvae. Each treatment began with 15 larvae.

RESULT

The following informations on the external morphology and habits of the lepidopterous insects feeding on *Podocarpus* may help to further studies the relationship of insects and plants.

1. ***Imma caelestis*** Meyrisk

Mature larve (fig.1)

Length 15-18mm; spindle-shaped, stout in middle and smaller at either end. Orange yellow, head, thorax and abdomen with black spots.

Head hypognathous, 7 stemmata one larger than remainder. Adfrontal areas almost reaching verticle, spinneret slender with rounded apex.

Spiracles on prothorax and abdominal segment 8 broadly oval and larger than on 1 to 7. Integument and pinacula densely and finely spinulose, spinules slender, acute, those around anus and on thoracic legs larger. Prothoracic and anal plate with spinules reduced, setae long with minute spicular branches, secondary setae absent.

Prothorax with three prespiracular setae, L1, L2, and L3 on one pinaculum. SV group bisetose on one pinaculum, Meso-and metathorax with D1 and D2 on one pinaculum, D1 posterodorsal of D2, SD1 and SD2 on one pinaculum, SD2 posterodorsal of SD1. L1 and L2 on one pinaculum, and L3 on separate pinaculum, SV group unisetose, thoracic tarsi with two apical setae broadly spatulate and scale-like.

Abdomen with D1 setae closer together than D2 setae on segment 1 to 8, segment 9 with D2 setae on one pinaculum and D1 closer to and on same pinaculum SD1, SD1 on one pinaculum on segment 1 to 8, SD1 slightly anterior of dorsal to spiracle, L1, L2 and L3 on separate pinaculae on segment 1 to 7. L2 anteroventral of L1, segment 8 with L1 and L3 on one pinaculum and L3 on separate pinaculum, ventral to L1. SV group bisetose on abdominal segments 1, 2, and 7; trisetose on abdominal segments 3-6; unisetose on abdominal segments 9. 8, 9. Ventral and anal prolegs long and slender, anal prolegs extended posteriorly and conspicuous in dorsal view, ventral prolegs each with 14 crochets arranged in uniordinal mesoseries, and prolegs each with nine to ten uniordinal crochets.

Pupa (figs. 2 & 7)

Length 13-19 mm, somewhat compressed dorsoventrally, orange dorsally with black dots. Cuticle lightly sclerotized, appendages firmly fused to each other and body. Head with paired lobes partially underlying clypeus, maxillary papli reduced to minute triangular sclerite. Haustellum not reaching end of antennae, labial palpi well developed. Antennae not reaching tips of wings; thorax with wings extending about half-way over abdominal segment 4. Fore femora clearly visible, mid-tarsi extending just beyond the wing tips, prothoracic spiracles strongly produced and heavily sclerotized, mesothoracic spiracles not visible. Abdomen without spines, segment 4 to 6 movable in female, cremaster with

Figure 1. *Imma caelestis,* mature larva.

Figure 2. *Imma caelestis,* pupa.

Figure 3. *Imma caelestis,* adult.

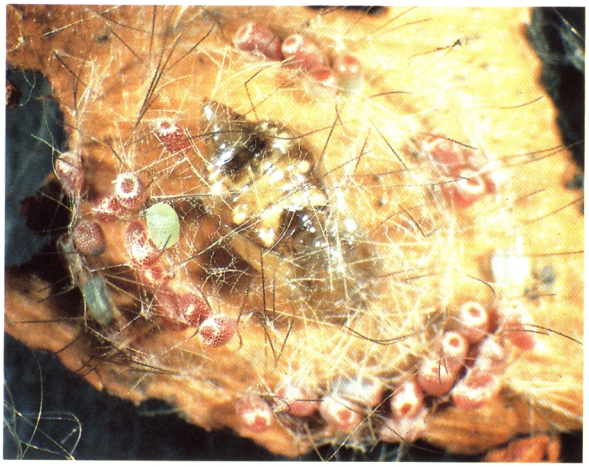

Figure 4. *Milionia basalis,* eggs.

Figure 5. *Milionia basalis,* larva.

Figure 6. *Milionia basalis,* pupa.

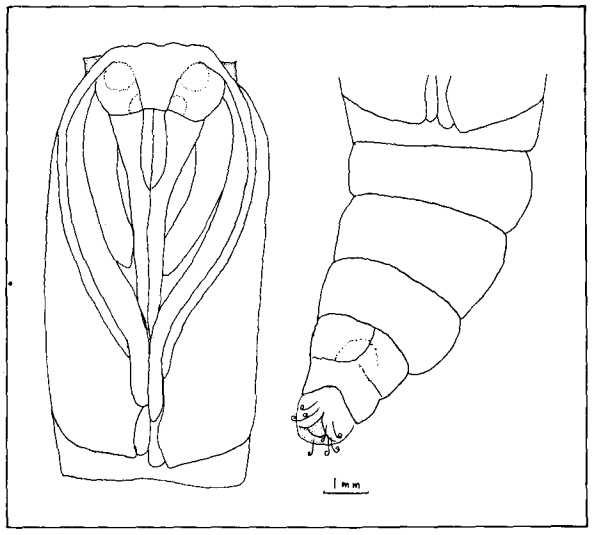

Figure 7. *Imma caelestis*, pupa.

about 14 hooked setae.

Adults (fig.3)

The formal description of the adult by Diakonoff (1986) is repeated below:

"Male, 36 mm. Head pale orange, vertex suffused with black. Antenna black, scape pale orange, cilia whitish. Palpus long, moderately thickened, basal segment porrected, median rectangularly rising, over 2.5 x as long as basal, spindle-shaped and smooth, terminal segment short, rather slender, subacute; light orange, median segment with a suffused frontal black streak along apical half, terminal segment black. Thorax dark grey strewn with pale orange scales, collar light orange, a pair of light orange submedian longitudinal streaks on anterior third, tegular with posterior half light orange. Abdomen orange, dorsum of segments 1 to 2 with an anterior black transverse streak, of fvie following segments with a semicircular anterior black spot, sides of segments 2-6 with a black, diagonal spot, venter with two sublateral rows of black anterior dots.

Fore wing obling-subtruncate, costa gently curved, apex rounded, termen rounded, vertical. Black, extreme costal edge yellowish-white; a vertical subbasal light range subtriangular spot, centred with black, convex anteriorly, posteriorly projecting in middle, concave above and below this, not reaching costa, limited below by vein 1b; a light orange marginal streak along dorsum, from beyond base to 1/4; a pattern of white streaks between veins from beyond base of diverse diameter, arranged thus: a narrow line above vein 12, a thicker a long basal half of upper edge of cell, continued along vein 11, becoming very thin along posterior half of the edge, continued above vein 10 and above vein 8; broadest above lower edge of cell and along discoidal vein and above vein 1b, this from base; finally moderately narrow above stalk and vein 7, vein 3 and 4 basal 2/3 of fold and basal half of dorsum. Cilia white, with a subapical greyish band.

Hind wing broad, rounded, almost 2, dark fuscous-bronze, on basal third becoming paler, costal 2/3 much paler; a yellow streak from base above vein 1c, not reaching edge of wing. Cilia snow-white, along dorsum fuscous.

Male genitalia: Tegumen membranous, top slightly narrowed, truncate, densely bristled. Uncus absent. Tuba analis long, membranous. Vinculum erected, illdefined. Saccus moderate, with a rounded top. Valva oblong-suboval, rather narrow; sacculus 3/4, rectangular at base, narrowed; moderately haired; cucullus concave below apex, with a down-curved apical densely haired process, closing cavity. Anellus sclerotized, a double-walled collar, with oval lateral lobes. Aedeagus long, S-shaped, top with a long, acute, ventral lip and a cylindrical, wide praeputium, coecum peins moderately flattened laterally, end excised, ductus seminalis caudal; no cornuti. Abdomen with slender V-shaped cerata behind sixth sternite and a small simple mappa at the end of the fifth sternite.

Female genitalia: Ovipositor short and broad, lobi anales rather united into a broad oval; postapophysis straight and short, antapophysis very short, slightly bent. Sterigma formed by the eighth sternite, a subquardrate concave sclerite being lamella postvaginalis, while its lower third folding frontally forms a semioval transverse lamella antevaginalis, so creating an ample ostium. Ductus bursae irregularly tortuous, with some three coils. Corpus bursae oblong-oval, with a finely reticulate wall. Signa two moderate oval sclerites, scobinate over inner surface."

Comments

Larvae of *I. caelestis* were collected on *P. nankoensis* in during October, 1988, and April 15, 1989 at Lien-Hua-Chi and reared in the laboratory of leaves of the host plant.

When disturbed, larvae of various sizes on the host plant (fig. 1), lower themselves on strands of silk, reascending to the leaves after a short while. Larvae usually feed on the upper surface of leaves, eating at their margins.

Pupation ocurred in a cocoon of orange silk spun in a shallow depression on underside of leaves of the host or nearby plants, or in crevices of the bark of the trunk. The larva first spins a thin layer of silk over the surface of the depression, followed by an irregular network across the depression forming a shallow cell. Toward one end of this covering is a narrow transverse opening. The pupal cremaster is anchored to the basal layer of silk, and is clearly visible through the outer silken covering.

Some larvae collected Februry 2, 1988 were parasitized by wasps in the families Braconidae (*Glyptapanteles* sp.), Eulophidae (*Tetrastichus* sp.), and Ichneumonidae (*Xanthopimpla* sp.).

The adult rests with wings held flat, only slightly bent at each side over the body. The antennae are held above the head, the tips slightly bent forward. Adults readily feed on a 5% honey solution. Adults have survived 10 days in the laboratory.

This is the first record of this species in Taiwan, with the overall size of specimens smaller than those found in China, about 30-32 mm wingspan. The fore-and hindwing, male and female genitalia are showed in figs. 9, 11, and 12 for comparison.

The very interesting genus *Imma* contains species with the appearance of Noctuidae, Hypsidae, Pyralidae, Arctiidae, and Zygaenidae. It is a genus of over 200 species, primarily tropical in distribution, but with a few palearctic species in the China, Japan, and Nepal. The Indomalayan region is the area of greatest diversity. Although there are many species of *Imma,* very little is known of their biology. Some tropical species feed on leaves of young shoots of *Ficus* species (Moraceae), living under thin webbing or between leaves. Some species pupate in cocoons consisting of an open network of silk, similar to those of the Choreutidae. (Diakonoff, 1986)

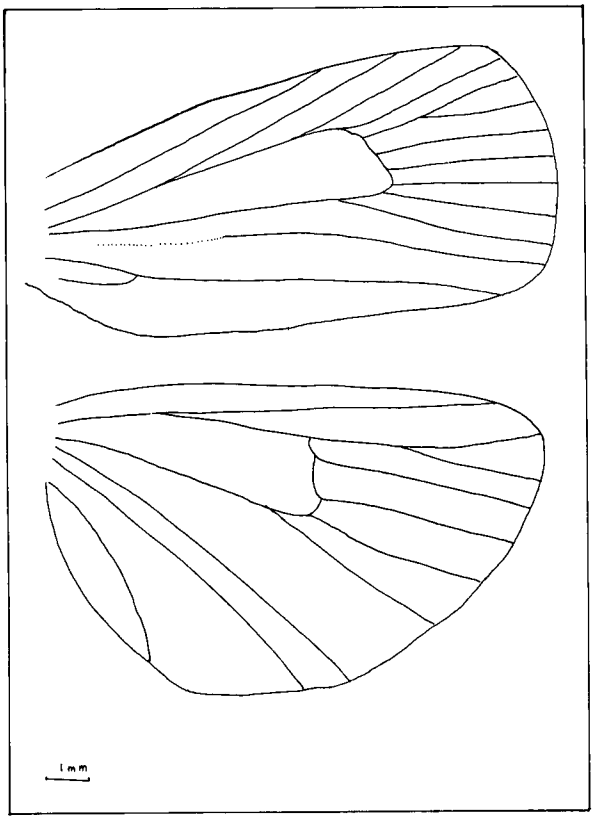

Figure 9. *Imma caelestis,* wing venation.

2. ***Milionia basalis*** Walker

Eggs (fig.4)

About 2×1.5 mm in size, oval, greenish, turn red and violet before hatch.

Mature larvae (fig.5)

Length 51 to 55 mm, slender and cylindrical; only primary setae present, head brown orange, thorax and abdomen orange brown with black spots and stripes. Head hypognathous, 6 stemmata, 2 large than remainder. Afrontal area not reaching the vertex, spinneret cone-shaped, with pointed apex. Spiracles on prothroax and abdominal segment 8 broadly circular and larger than on 1 to 7. Ventral and anal prolegs short and stout, each with 40 to 44 crochets arranged in biordinal.

Pupae (figs.6 & 8)

Length 24 to 26mm, brownish, cuticle

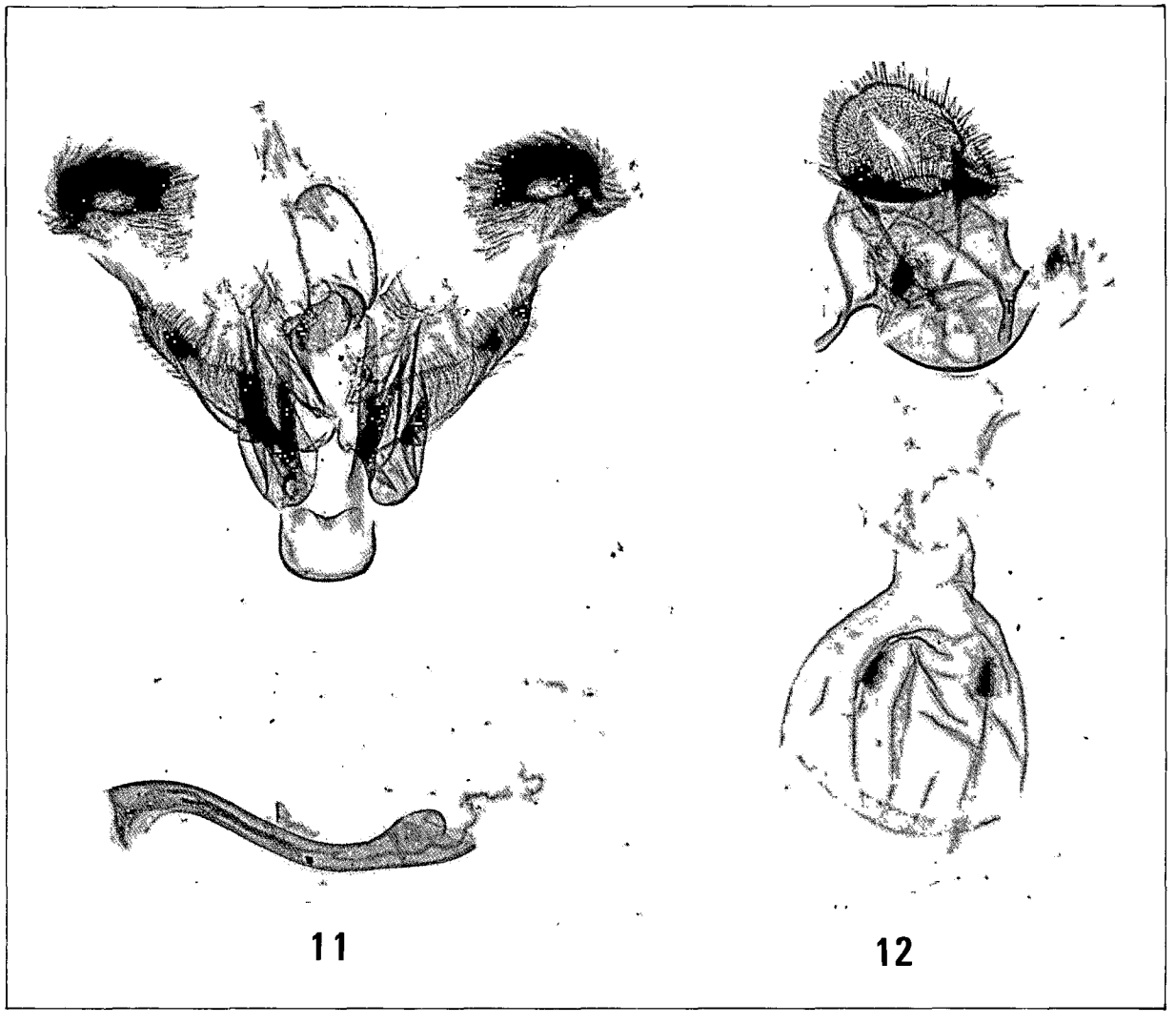

Figure 11. *Imma caelestis,* male genitalia.

Figure 12. *Imma caelestis,* female genitalia.

sclerotized, appendages fused to each other and body. Head with paired lobes underlying clypeus, maxillary palpi reduced to a minute sclerite or possibly absent. Haustellum almost reaching end of antennae, labial palpi well developed. Antennae reaching tips of wings, thorax with wings extending about two third over abdominal segment 5. Fore femora clearly visible, mid tarsi almost raching tips of antennae, hind tarsi extending to tips of antennae and beyond the wing tips. Thoracic spiracles not visible. Abdomen without spines, spiracles produces, cremaster with two pointed spines.

Adult.

The original description by Walker (1854):

"Bright blue. Proboscis and antenae black. Thorax partly brownish black. Abdomen brownish black with a blue band on the hind border of each segment. Legs, partly black. Wing black, streaked with bright blue towards the base. Forewings with an obligue and slightly curved orange band in the middle; its hind end contiguous to the orange band near the tips of the hind wings in the male; borders of the nind wings of male with orange spots."

Male, female, 44-48mm, head bright blue,

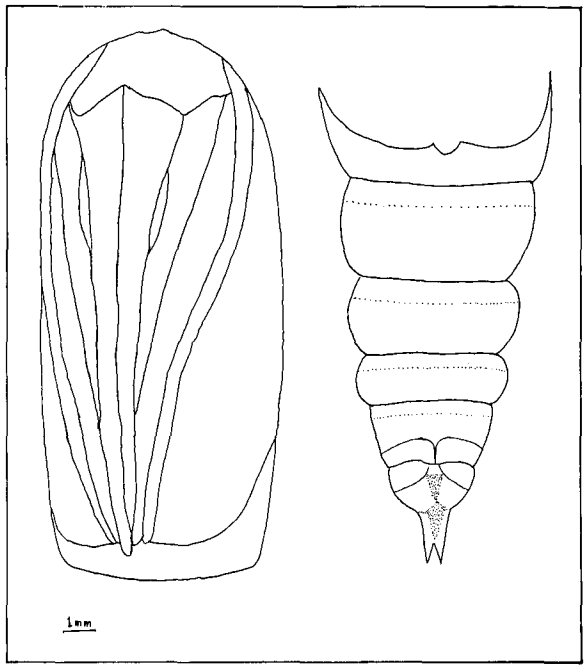

Figure 8. *Milionia basalis,* pupa.

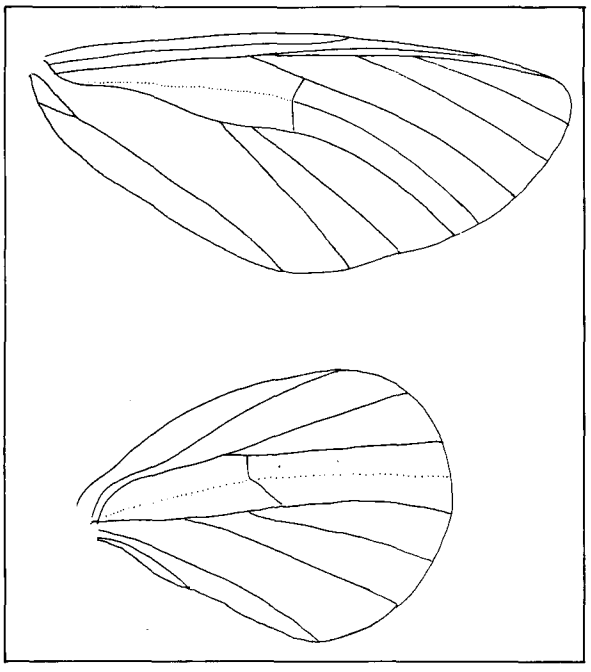

Figure 10. *Milionia basalis,* wing venation.

antennae black, cilia whitish. Palpi bright blue, porrect, second joint small triangle, terminal joint very short. Proboscis black. Thorax and abdomen bright blue. Wing black, streak with bright blue toward the base. Forewing with an oblique and slightly curved orange band in the middle. its hind end contiguous to the orange band near the tips of the hind wings in the male, border of the hind wings of male with orange spots (fig.10)

Male genitalia: Uncus bifid. Valva broad, rectangular, distal end with about 15 spines, in the middle with about 14 spines in two rows. Aedeagus short, cylindrial, slightly sclerotized (fig.13).

Female genitalia: Ovipositor narrow, anal lobe not united. Posterior apophysis and anterior apophysis long and straight. Corpus bursae oval with, signa with round sclerites, with many projection, star shaped (fig.14).

Comments

Eggs collected on October, 1989 by the author at Wushe, Nantou, Taiwan on *P. nankoensis.* Eggs laid singly under the cracked bark, lichen covered crevices, intersection of branches, and some debris of old leave hanging on the branches of the of the host plant. Egg stage about 3-4 days.

First instar larvae green, with head and last 2 segments brown, 6 ± 1 mm in length, thoracic legs and prolegs yellow. The size of the other stage and life history are as following:

Egg	2×1.5 mm	3.4 days
1st	5-7 mm	3-5 days
2nd	15-23 mm	2-3 days
3rd	23-28 mm	2-5 days
4th	33-40 mm	5-8 days
5th	50-55 mm	8-10 days
Pupal		10-15 days

Larvae feed on upperside of the leaves. If disturbed, lower themselves on strands of silk on the ground or in the wind and reascending to the trunk or the foliage. Mature larvae crawl to the ground usually near the tree and pupated (fig.6).

Larvae collected at Wushe, Nantou, in October, 1989 were parasitized by the wasps in the families Braconidae *(Cotesia* sp.), and Ichneumonidae (*Xanthopimpla nana aeguabilis* Krieger).

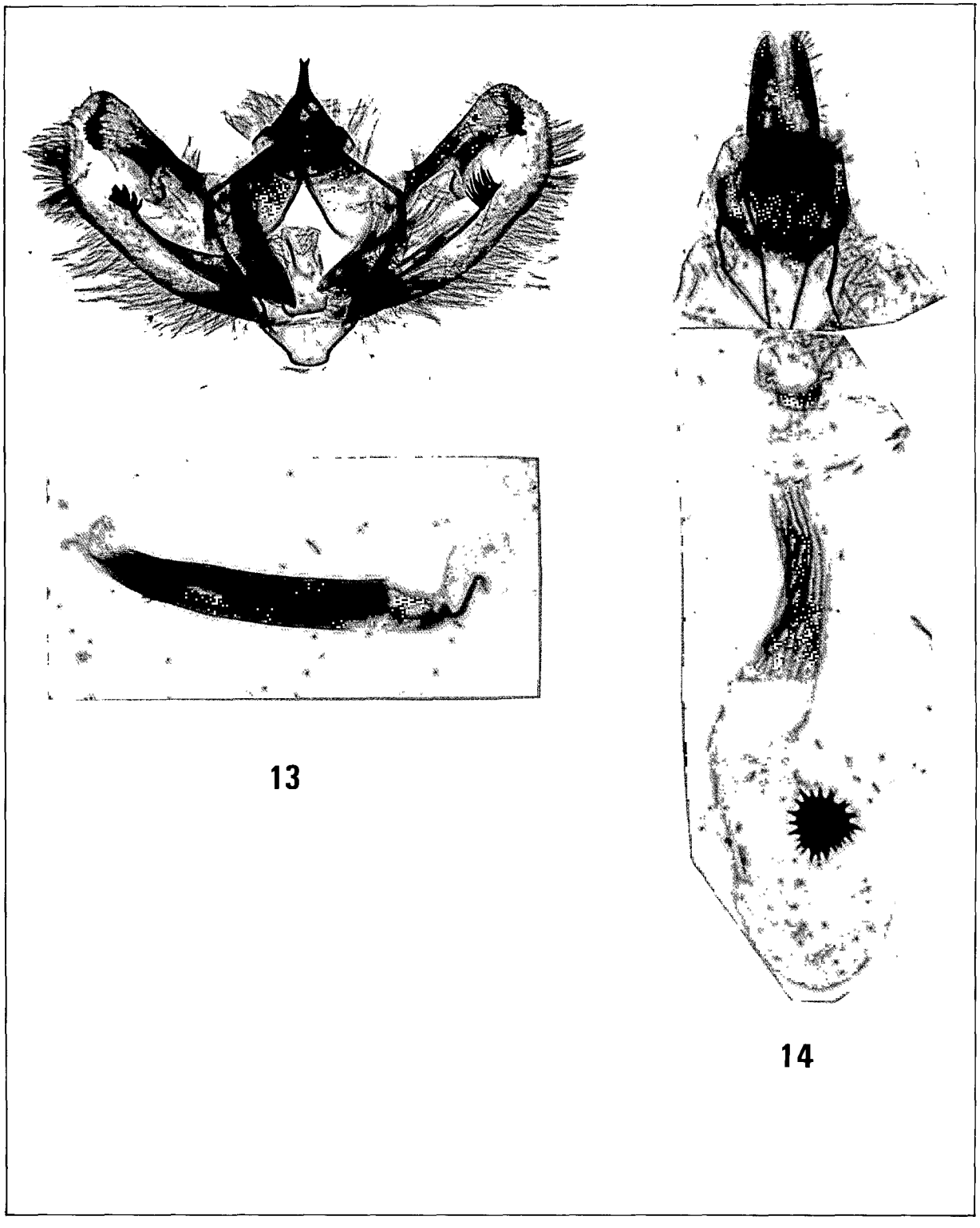

Figure 13. *Milionia basalis,* male genitalia.

Figure 14. *Milionia basalis,* female genitalia.

Adults are day flier, flying slowly like a butterfly, very active at dusk. lay eggs in the day time, female touch the tree with ovipositor first and then lay eggs. Eggs are laid singly. Adults are found in Tienshaun, Hualien; Kukan, Taichung; Wushe, Sun Moon Lake, Lien-Huā-Chi, Nantou. In Taiwan the food plants of this insect include *P. nankoensis* and *P. macrophylla* (Podocarpaceae).

According to Inoue (1982) this insect is distributed in Japan, Taiwan, Hainan, Java, Borneo, Sumatra, Malaya, India. In Japan the foodplant of this insect is *P. macrophylla.*

Bioassay using extracts from *P. nankoensis* and frass of *M. basalis* feeding on *P. nankoensis* are using test insects, *B. mori.* larvae fed on leaf extracts from *P. nankoensis* died 8 days later. There were no external symptoms shown in those test insects that died in the pharate condition. *B. mori* larvae fed on fecal extracts from *M. basalis* larvae feeding on *P. nankoensis,* all died after 9 days. One of the test insects showed significant external symptoms while in the pharate condition. Test insects fed on leaves previously dipped in ethyl acetate solvent or distilled water pupated after 10 days, although two larvae died of diarrhea because of bacterial disease.

The larval frass of the test insects in each treatments are collected. Test insects in the control studies have 6.09 g and 5.44 g larval frass respectively. Test insects fed on leaves with fecal extract or leaf extract have 2.22 g and 0.93 g of larval frass respectively. Test insects in the treatments have less appetite for feeding and have less larval frass than the insects in the control studies. The fecal and leaf extract may have some deterrent effect to the feeding of the test insects. Test insects may died of starvation.

DISCUSSION

Podocarpus is the principal southern genus found in the rain forest. It has a very ancient relationship with the territories where it still exists. The gymnospermous *Podocarpus* show the distinctness of temperate southern Africa, and also South America, and Australia (Pielou, 1979; Florin, 1963).

Imma spp. which numbers over 200 species, is typical of the circumtropical group. A small number of species are distributed in the Palearctic (such as Nepal. China, and southern Japan), but these are probably intruders from the subtropics and tropics (Diaknoff, 1986).

Milionia contains 40 or more species, many of which have formed local races in different islands, differing in details of color or pattern. Most of the species occur in New Guinea or surrounding islands. A few are found in Indonesia, and is found as far North as Japan (Watson & Whalley, 1975).

Distribution of *Podocarpus* spp., *Imma* spp., and *Milionia* spp. are given in fig. 15. *Podocarpus* spp., *Imma* spp., and *Milionia* spp. are southern genera. *Milionia* spp. is distributed in the Indo-Malayan region.

Podocarpus has considerable amounts of phytoecdysone. Few insects feed on this plant. Two insects, *I. caelestis* and *M. basalis* have become adapted to the phytoecdysones in their host plants. However, *B. mori* fed on the fecal extract of the *M. basalis* died in the pharate condition. This suggests that *I. caelestis* and *M. basalis* have developed mechanisms to protect against the toxic effects of the phytoecdysones.

I. caelestis and *M. basalis* both feed on *Podocarpus.* The two insects are belong to different taxonomic families. They have some similarity morphologically, biologically, and ecologically. Both larvae and adults have showy, bright color with black streaks or spots. Adults are day-fliers. Larvae are easy to detect. Caterpillars may acquire chemical compounds from their host plants which render them unpalatable to their own predators. These compounds may be sequestered through to the adult stage, making the adults unpalatable as well. Further studies are needed to evaluate the significance of chemical compounds as a defense mechanisms for larvae and adults to fully understand the ecology of the lepidopterans.

According to field observation by the author, females of *M. basalis* lay eggs in July. The outbreak of this species is in October-November and will cause defoliation of the *Podocarpus* plant in winter. In the early spring, the plant sprouts and have new leaves. Leaves matur after 2 or 3 months. The insects usually feed on the mature leaves instead of the immature leaves. Nitrogen and water content are highest early in the season, when soft immature leaves or seedlings are well protected with the phytoecdysones. As the season progresses, nitrogen and water content decrease, as the leaves toughen

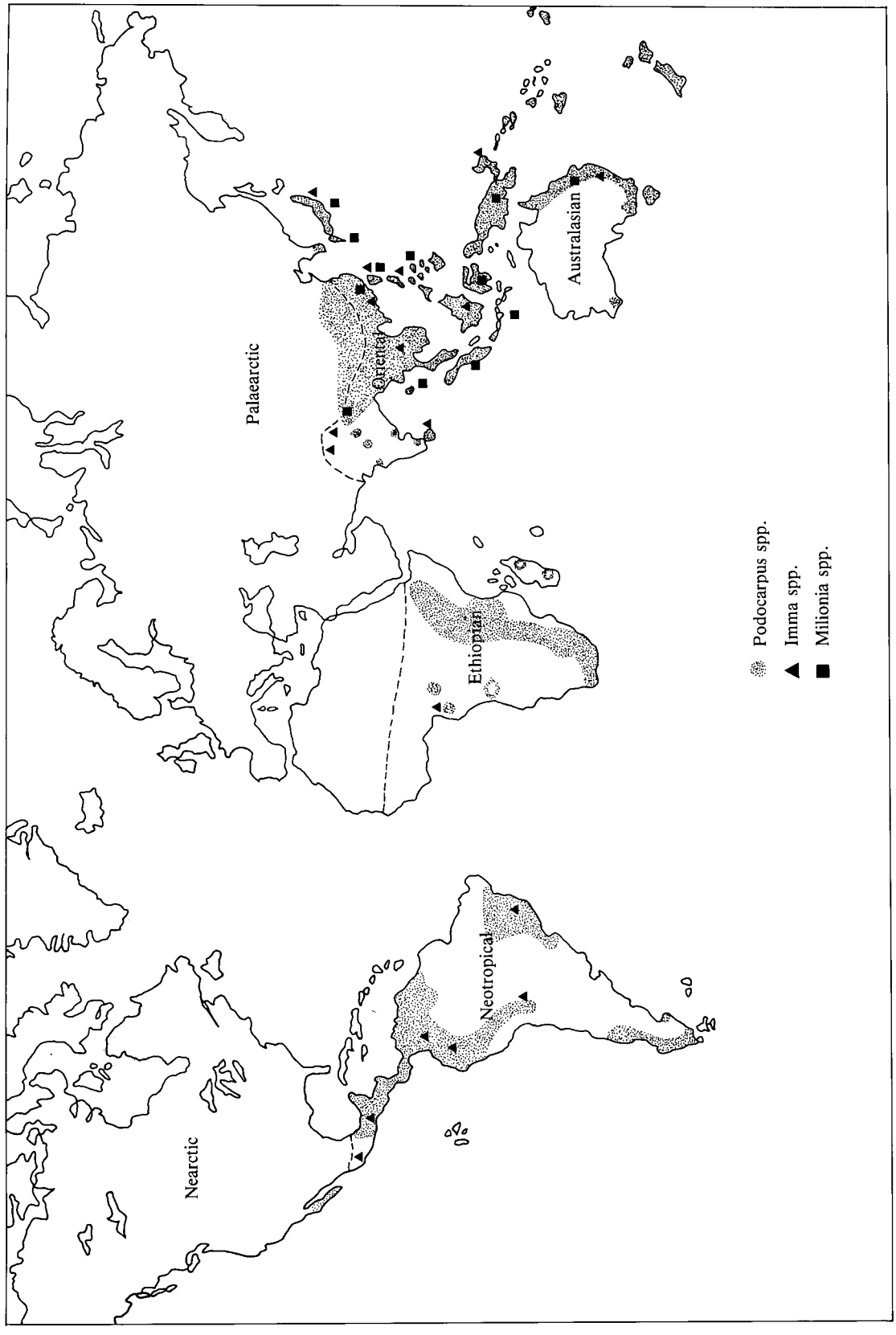

Figure 15. The distribution of *Podocarpus* spp., *Imma* spp., and *Milionia* spp..

and become less nutritious. The decrease in nutritional quality follows a drop in phytoecdysone content (Scriber, 1984). Insects probably choose the mature leaves instead of the immature ones to escape the higher content of phytoecdysones in immature leaves.

Podocarpus spp. are distributed in the mountainous area over 600 m elevation in Taiwan. The cool weather in winter may influence the metabolism of the plant. *Podocarpus* is an evergreen plant. Its defoliation by insects does not influence the meristematic activity. In fact, the defoliation may help in saving energy for the plant during the winter. It may trigger the vigorous growth of new leaves the next year. This insects and plants may interact beneficially and be mutually coadapted. Further evidence is needed to support the relationship between plant and insect.

SUMMARY

Podocarpus is a gymnosperm which is largely distributed in tropical and temperate regions. Compounds isolated from this plant are related by structure and activity to the ecdysones. The biological basis for this plant having developed the ability to elaborate steroids with insect molting hormone activity is still unknown.

Two caterpillars, *I. caelestis* and *M. basalis,* successfully develop and reproduce while feeding on plants contain phytoecdysone. The morphology, biology, and ecology of these insects were previously unknown and are reported in this paper.

Bioassay of the leaf and fecal extract of *M. basalis* on *B. mori* (whose nautral host plant is mulberry, not *Podocarpus)* showed that *B. mori* died in the pharate stage. Apparaently, *I. caelestis* and *M. basalis* have become adapted to the dietary supply of phytoecdysones in the plants by evolving efficient method of metabolizing and excreting phytoecdysones. Further studies are needed on the larval and adult chemical defense mechanisms and the cost of these mechanisms, in terms of energy to the insects, in order to better understand the ecology of these lepidopterans.

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取食竹柏之鱗翅目幼虫

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摘 要

本文描述取食竹柏之兩種鱗翅目昆蟲幼蟲及蛹之形態及其生活習性，並將竹柏葉及幼蟲糞便之乙酸乙酯溶劑抽取液塗抹於桑葉上餵飼家蠶，造成家蠶高死亡率，處理組比對照組取食量及排糞量少，塗抹液具有厭食性化合物或由於脫皮不正常而餓死仍有待研究・

竹柏含類似昆蟲脫皮素之物質影響昆蟲發育・取食竹柏之昆蟲可利用竹柏葉當食料・在生態及演化上有顯著之意義，值得繼續研究・