

**A BIONOMIC STUDY OF BAGWORMS
(LEPIDOPTERA: PSYCHIDAE) IN SELECTED AREAS
OF KERALA**

Thesis submitted to the
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for the Award of the Degree of
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By

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This is to certify that all the corrections/suggestions (minor) recommended by the adjudicators have been incorporated in the Ph.D. thesis of Ms. Usha AU, titled "A BIONOMIC STUDY OF BAGWORMS (LEPIDOPTERA: PSYCHIDAE) IN SELECTED AREAS OF KERALA" and that the contents in the hard copy of the thesis and the soft copy (CD) are one and the same.

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DECLARATION

I, Usha A U, hereby declare that the thesis entitled “**A Bionomic Study of Bagworms (Lepidoptera: Psychidae) in Selected Areas of Kerala**” submitted to the University of Calicut for the award of the degree of Doctor of Philosophy in Zoology is a bona fide record of the original research work carried out by me under the guidance of **Dr. Joyce Jose**, Assistant Professor, Department of Zoology, St. Thomas College (Autonomous), Thrissur and that it has not been submitted earlier either in part or full for the award of any degree previously.

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APPENDIX B(a): The details of sites visited in the study areas

APPENDIX B(b): Details of bagworms and hostplants from different sites visited in the study areas

LIST OF ABBREVIATIONS USED

RGCB	Rajiv Gandhi Centre for Biotechnology, Trivandrum
NCBI	National Centre for Biotechnology Information, Bethesda, Maryland, USA
BLAST	Basic Local Alignment Search Tool
EI	Eye-Index (Smallest eye distance / vertical eye diameter in anterior view)
WI	Wing-Index (maximum length base to apex divided by the maximum width)
EPI	Epiphysis index
dc	discal cell
<i>et al.</i>	<i>et alii</i> -- and others
sp. nov.	species nova -- new species
leg	legit -- he, she, or it collected
cf.	confer -- compare with
sp.	species
mm	Millimetre
mASL	Meters Above Sea Level
♀	female
♂	male

ABSTRACT

Moths are the most diverse group of insects in the animal world. More than 90% of discovered Lepidopterans are thought to be moths, while many of them are still unknown. Psychidae is one of five moth families that make up the Super Family Tineoidea. Members of the Family Psychidae are commonly called bagworms, bagworm moths or bag moths because of their bag-making behaviour. Different types of materials such as silk threads, plant twigs, leaves, bark tissues, algae, mosses, grass, lichens, animal debris, etc are used to build the bag around the larval bodies. Female moths of many bagworm species complete their life cycle inside their bags and do not develop as adult moths. The bagworm family consists of 10 subfamilies. There are 1450 described species from 241 genera reported from all over the world.

The study was conducted in different human inhabited/anthropogenically areas in all districts of Kerala. The present study documented 26 bagworm species belonging to six subfamilies from the study area of which 14 species were identified up to the species level, three up to the genus level and nine species are unidentified. The list includes the reports of one new genus (*Capulopsyche*) and three new species (*Eumasia thomasii*, *Eumasia venefica*, *Capulopsyche keralensis*) and one species rediscovery and neotype designation from Kerala, India. All species were classified based on their feeding habits. Subfamily Oiketicinae was the most dominant group with eighteen species belonging to seven genera. Based on the major morphological characters a taxonomic key for the 10 identified genera of Psychidae moths from the study area was prepared.

Detailed descriptions of the bags of all the species of the study area were made along with photographs and detailed diagrams. The identification key to all the identified species bags was prepared. This can serve as an essential resource for agriculturalists, administrators and policymakers because they are unable to distinguish this potential pest from the surroundings of farmed area because of its unique life history. Seventy-three hostplant species belonging to thirty-eight families were found infested by nine identified bagworm species from the study area. Some species showed voracious feeding on plants while others depend on the plants only for their pupal bag attachment. Younger stages of larvae of bagworms preferred herbs and shrubs for feeding and the last instars used trees for attaching their pupal bags. The species richness of bagworms was higher in *Phyllanthus emblica* and *Lagerstroemia speciosa* as five psychid species

were observed in these plants. *Eumeta crameri* followed by *Manatha albipes*, *Acanthopsyche alstoni* and *Metisa canifrons* infested maximum number of plant species. Distribution mapping of all the identified species was done using the open-source software QGIS. Threat analysis was done by comparing the distribution areas of these species and their economically important host plants. One dipteran parasitoid (*Nealsomyia rufipes*) and seventeen hymenopteran parasitoids and one hymenopteran predator which infest bagworms were recorded.

Life cycle studies of the species *Eumeta crameri* and *Metisa plana* was done. *Eumeta crameri* had 4 instars. Based on the current observations the average lifecycle of *Eumeta crameri* was 67.6 days in duration. *Metisa plana* had 6 instars and the total lifespan varies between 52 to 79 days (neonate-adult). The percentage of emergence from pupal bags was calculated for other species. Consistent monitoring of the life cycle and life history traits of all the economically important bagworm species is important for a better understanding of their biology and pestilence potential across different habitats and climatic conditions. Extensive and intensive surveys can bring to light many species new to science. Therefore, further studies are recommended.

CHAPTER 1

General Introduction

CHAPTER 1

General Introduction

1.1. Introduction

Moths and butterflies come under the order Lepidoptera. Scaled bodies and scaled wings are the significant characteristics of this order. Historically suborders Rhopalocera and Heterocera have been used to classify lepidopterans into two groups even though such usage is no more prevalent. It would be better to say that all lepidopterans that are not butterflies are moths and are differentiated from butterflies by the presence of diverse types of antennae, unlike butterflies that have thin clubbed antennae. Moths are a paraphyletic group. It has been estimated that there are about 160000 described and undescribed species of moths worldwide (Singh *et al.*, 2022).

Psychidae is one of five moth families that make up the superfamily Tineoidea of Lepidoptera's most successful and recently developed Clade Ditrysia (Davis *et al.*, 1998) along with the families Dryadaulidae, Eriocottidae, Tineidae and Meessiidae (Regier *et al.*, 2015, Roh *et al.*, 2020). Members of the family Psychidae are commonly called bagworms, bagworm moths or bag moths because of their bag-making behaviour (Sugimoto 2009a, b; Roh and Byun, 2016). The larval stages of these moths make bags around their body with different types of materials such as silk threads, plant twigs, leaves, bark tissues, algae, mosses, grass, lichens, animal debris, etc. The majority of the female moths even complete their life cycle inside their bags. The bagworm family consists of 10 subfamilies. There are 1450 described species from 241 genera reported from all over the world except Antarctica (Sobczyk, 2011, 2019; Nieuwerkerken *et al.*, 2011). Hampson (1892) listed 36 species from British India including Sri Lanka and Myanmar and is supposed to be the oldest record of bagworms from India. A recent checklist indicates the presence of 106 species belonging to 34 genera in India (Sobczyk, 2011). Most bagworms exhibit an astonishing life history (Fabre, 1900; Guilding, 1827; Leonhardt *et al.*, 1983) with the species showing extreme sexual dimorphism. Only the male insect emerges as a winged moth from the bag while the females are apterous or brachypterous and persist as an egg sac inside the bag. In some species, females are wingless and have rudimentary appendages. (Saigusa, 1962; Rhainds *et al.*, 2009).

1.2. General characters of Family Psychidae

Moths of the family Psychidae are small to medium in size, with forewings varying from 4 to 28 mm in length. Adult females are either completely winged, brachypterous, apterous or vermiform (with all body appendages vestigial or lost) and males are usually fully winged. As adult females have shortened wings and legs, they move less or are completely immobile after reaching maturity. The only activity they do is egg laying. The female pupa has a lower diagnostic value when compared to males (Rhainds, *et al.*, 2009). The morphology of the larval stage is conservative with (a) four pairs of epipharyngeal setae (b) the pronotum expanded laterally and fused to the lateral pinnaculum to include the spiracle and all three pre-spiracular setae and (c) abdominal crochets on segments 3–6 arranged in a uniordinal, lateral penellipse, all of which indicate the family's monophyly (Davis, 1987, Rhainds *et al.*, 2009).

Females of twentyfive families of Lepidoptera show wing reduction or degeneration (Sattler, 1991, Niitsu and Kobayashi, 2008) and in Psychidae both adults with wings are included in the primitive lineages (Saigusa, 1962). Therefore, it is suggested that adult females with wings have undergone less evolution compared to other female Psychids with apterous and brachypterous conditions. Saigusa (1962) suggested a grade of classification of female bagworms based on the degree of the wing and leg reduction, oviposition and structure of the ovipositor further improved by Niitsu and Kobayashi (2008) (Table 1).

Table 1: Grade of classification of female bagworms: Source: Niitsu and Kobayashi (2008)

Grade of classification	Characteristics
α	Well-developed wings and legs
β	Degenerate wings, short legs but non-functional, and adult female moults outside the larval case
γ_1	Similar to β grade degree of the wing and leg reduction and female moults inside the larval case
γ_2	A similar degree of wing and leg reduction as β and the last abdominal segment remains inside the larval case
δ	Females are vermiform, apterous and without any appendages

1.3. Significance of the study

The biology of bagworms is uncharacteristic of insects in general. Bag building in larval stages, reduction of appendages in females and extreme sexual dimorphism are interesting in themselves. Despite eruptive population dynamics and mating failures (Rhiands and Sadof, 2008), predator and parasitoid attacks and shrinking habitats their continued survival itself is a wonder. Work on the taxonomy, diversity and life history has been negligible in the study area because of the difficulty to identify using external phenotypic markings, unlike larger taxa. Also, nocturnal habits, unique life history and camouflage of bags cause these moths to remain unnoticed unless they are pests.

The handful of studies in the study area focus on pestilent species. Understanding of the population dynamics and individual and community fitness is essential for pest management, especially in the light of climate change-driven emerging pestilent species.

Bagworm moths are poly phytophagous with several species being defoliating pests of crops in tropical countries, especially in monoculture plantations (Basri, 1993; Zalucki *et al.*, 2002, Shah *et al.*, 2015).

In Kerala, the damage by bagworms to agricultural or forestry plantations is minimal or unrecognized but in areas with comparable environmental circumstances like Malaysia, oil palm plantations have incurred significant economic losses. The presence of suitable host plant species, adaptable environmental conditions, climate change, habitat modification and the introduction of exotic species can transform a potentially harmless pest into an organism with serious infectivity and may lead to serious pest outbreaks.

Even though bagworms have not yet become a significant pest in Kerala poor agroforestry practises, habitat disruptions and climate change can change its pest status. Paucity of information and lack of continuous monitoring has resulted in a gap in the current scientific literature based on thorough investigations of bagworms from Southern India. Research on bagworms in India and Kerala are primarily focused on forests (Nair, *et al.*, 1981; Mathew and Nair, 1983, 1986). No information is available regarding how these harmless, but potentially dangerous moths exploit plants in

uncultivated areas close to human habitations. In an unmonitored location, the bagworm population or any pest, for that matter may serve as a breeding ground for a pest invasion that could harm agricultural crops economically. Information on how these moths use the plants as hosts might be helpful in controlling them.

1.4. Gaps in the existing knowledge

The world catalogue of Psychidae (Sobczyk, 2011) lists 106 species from 35 genera from India. These species were listed from the records based on old studies by Lepidoptera experts in British India. Many of the species' descriptions such as that of *Clania holmesii*, *Acanthopsyche alstoni*, were based only on the presence of larval cases. A checklist was published by the Zoological Survey of India based on the published data of bagworms in India without any descriptions and photographs (Shah *et al.*, 2015).

A study by Mathew and Nair (1986) listing 17 species including 4 undetermined species and their hostplants from Kerala is the only published record of this insect group from the study area. The checklists and reports also present incorrect data in light of recent developments in integrative taxonomic tools as some taxa were misidentified or even placed in a different higher taxon, previously. The checklists and many unpublished reports in many cases also lack full descriptions of adult, larval stages and the cases. They do not include good-quality photographs or drawing which in turn would facilitate the identification and further study.

1.5. Purpose of the study

Within this frame of reference, the present study focuses on the bionomics of the family Psychidae, which includes the taxonomy, distribution of the species in the study area, host plants, and their ecological aspects. The study was conducted in anthropologically altered areas in Kerala, from where the documentation of this insect group was not done earlier. It is expected that documentation of the hostplants of bagworms will provide new information on infestation and threats caused by these species in the study area. Thus, this study aims to provide comprehensive information of Psychids in non-forested regions of Kerala.

1.6. Objectives of the study

In the above context, the objectives of this study are:

- 1. To make the checklist of bagworms in the study area**
- 2. To study the taxonomy of bagworms in the study area**
- 3. To study the bag architecture of the species**
- 4. To study the distribution, host plants and do threat analysis of selected bagworm species**
- 5. To study the life cycle of selected bagworm species**

CHAPTER 2

Preliminary Checklist of Psychidae in Kerala

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Preliminary Checklist of Psychidae in Kerala

2.1. Introduction

Moths comprise 129 families and 41 superfamilies and makeup almost 90% of all lepidopterans. There are approximately 13,500 species of moths in India out of the approximately 160,000 species recognized worldwide (Singh *et al.*, 2022). There has been copious research on the Heteroceran fauna of India in previous centuries (Hampson, (1892-1896), Moore (1882-87), Bell & Scott (1937) and Cotes & Swinhoe (1887-89). In recent years, few studies have documented the moth diversity of the entire India (Kirti & Singh 2016; Shubhalaxmi, 2018). From Kerala, an exhaustive study listed 844 species belonging to 34 families of moths (Balakrishnan, 2020). Other studies from Kerala have mostly focused on regions like Silent Valley (Mathew & Rahmathulla, 1995), Vagamon Hills (Mathew *et al.*, 2018) Shendurney and Ponmudi in Agastyamalai Biosphere Reserve (Sondhi *et al.*, 2021) and Kawai Basin (Alex *et al.*, 2021).

Psychids being very small in size and having peculiar biology are difficult to sight. Even when sighted, captured or reared they are difficult to identify by external phenotypic markings. Rhiands *et al.* (2009) hypothesized that host preference could be induced through larval experience as demonstrated in that study where many psychid species supposed to be poly phytophagous experienced larval death when transferred to another plant species during laboratory rearing experiments. This means that even though larval bags are collected and reared, adults may not be obtained to confirm identification as per IUZN rules. Therefore, it is no wonder that the studies mentioned above have not listed many psychids from the region (Appendix A).

2.2. Review of literature

The bagworm family has 10 subfamilies, and 1450 described species from 241 genera globally except Antarctica (Sobczyk, 2011, 2019; Nieuwerkerken *et al.*, 2011). Hampson (1892) listed 36 species from British India including Sri Lanka and Myanmar and is supposed to be the oldest record of bagworms from India. Other studies were also present to document this group from India (Watt & Mann, 1903; Moore, 1882-87;

Meyrick, 1910,1911,1919). The World Catalogue of Psychidae records 106 species belonging to 34 genera from India (Sobczyk, 2011; Shah *et al.*, 2015).

Studies of bagworms from Southern India (Ayyar, 1940; Nair, 1978; Nair *et al.*, 1981; Mathew and Nair, 1983 1986; Varma *et al.*, 1989; Nair and Mathew, 1992) mainly focus on individual species, their potential as pests and control measures. Seventeen species of bagworms from Kerala including four undetermined species along with their host plants and their potential as pests of different economically important trees (Mathew and Nair, 1986). Five species of bagworms (*Metisa plana*, *Eumeta crameri*, *Brachycyttarus* sp, *Pteroma plagiophleps* and *Thyropteryx* sp) along with their host plants were reported from Peechi – Vazhani wildlife sanctuary, Kerala, India (Mathew *et al.*, 2005). Two new records of bagworms in India namely *Mahasena graminivora* and *Pteroma plagiophleps* (Pandey and Singh, 1994; Santhakumaran *et al.*, 1995) were also published.

Recent reports of bagworm moths from India other than checklists include (Induria, *et al.*, 2022; Usha *et al.*, 2021; Poorani *et al.*, 2021; Agrawal & Pati, 2003, 2002 a, b; Agrawal *et al.* 1997). Occurrence of bagworm species *Pteroma plagiophleps* Hampson and *Clania* sp. in cocoa crops were reported from Andhra Pradesh and the infestation was observed like a central concentrated patch in the cocoa plantation (Emmanuel *et al.*, 2010). The bagworm *Pteroma plagiophleps* Hamp was reported for the first time from the mangroves in Chettuvai, Thrissur district. Severe infestation occurred in the plants such as *Rhizophora mexicana* and *R. mucronata* (Therattil, 2013).

2.2.1. Psychidae from all over the world

A comprehensive review on the bionomics of bagworms citing 116 references (Rhainds *et al.*, 2009) discussed the life history traits of 18 species of bagworms. Davis (1964) published a book on bagworms in Western Hemisphere which listed the European species of bagworms. Sauter and Hättenschwiler (1999) published a distributional checklist of Psychidae in Europe. In 1864, Walker described the genus *Degia* with the two species *D. imparata* and *D. deficiens* from Malaysia (Sobczyk, 2009). Thirteen species of bagworms were listed in the state of Texas (Jones and Parks, 1928) including an additional three species presence listed in the “anticipated” category. But later four were recognized as the synonyms of some species and two were apparent errors and a total of seven species were recorded from Texas (Davis, 1964). The first Texas record

of one of the “anticipated” species has been reported in 1976 (Neck, 1976a, b) and had well-described bionomic notes of five species of bagworms reported from Texas. The five species included *Thyridopteryx ephemeraeformis*, *Oiketicus abbotii*, *Cryptothelea gloverii*, *Astala edwardsi*, etc. Another five new species of bagworm moths were reported from Cuba and their characteristics confirm the intermediate position of the genus among the American Psychids. The species are *Paucivena ferruginea*, *Paucivena pinarensis*, *Paucivena fusca*, *Paucivena cubana* and *Paucivena orientalis* (Aguila, 2006). In southeast Asia *Mahasena corbetti* Tams and its widespread distribution from Thailand, Peninsular Malaysia, Sumatra, Java, Borneo (Brunei, Sabah), Solomon Islands, and Samoa (Robinson *et al.*, 1994), and Singapore (Leong and Lim, 2012) was reported. *Mahasena andamana* Moore was reported only from the Andaman Islands (Robinson *et al.*, 1994; Pitkin and Jenkins, 2003). The first report on *Mahasena aurea* was from Korea in 2015 with pestilence on the medicinal plant *Liriope spicata* (Roh and Byun, 2016).

The species *Bacotia sakabei* from Korea with systematic accounts and morphological features of this lichen-feeding bagworm species (Roh and Byun, 2016) was recorded. Three species of *Bacotia* have been recorded globally (Sobczyk, 2011; Saigusa and Sugimoto, 2013). A new genus somewhat resembles *Bacotia* has been described from Taiwan, named *Tayalopsyche* gen. nov. based on the new species *Tayalopsyche spinidomifera* sp.nov. (Saigusa and Sugimoto, 2022). It was not included in the subfamily Oiketicinae because of the differences in the wing venation patterns, so the authors put the genus into the subfamily Psycheoidinae Kozhanchikov (1969).

2.2.2. New species discoveries in the last decade from all over the world

There have been many recent additions to the genus and species in the family Psychidae worldwide. Two new species additions to the genus *Metura* (*Metura phyllosacca* sp. N. and *M. falcata* sp. N.) were reported from Australia with the revision of the genus (Beaver, 2020). Roh *et al.*, (2018) reported the genus *Dahlica* Enderlein from Korea for the first time, with two new species *Dahlica somae* sp. nov. and *Dahlica ochrostigma* with detailed illustrations of adults and DNA barcodes of the species. A recent report has listed 21 species of bagworms from Russia with two new records (Volkova *et al.*, 2022), of *Apterona helicoidella* Vallot (1827) and *Dahlica clathrella* Fischer (1837). A new primitive genus named *Lepidoceropsyche* gen. nov. and its type species *Lepidoceratopsyche manoi* have been described from Japan (Saigusa and

Sugimoto, 2022). Saigusa and Sugimoto reported a Nearctic genus *Kearfottia* Fernald from the Palaearctic region, Japan, and the described new species *Kearfottia japonica* was the second species of this genus in the world after the Nearctic species, *K. albifasciella*. (Saigusa & Sugimoto, 2021). A new species *Dahlica navacerradensis* Sobczyk is described in central Spain (Sobczyk, 2014). A new genus *Guttulapsyche* and new species *Guttulapsyche mayaensis* were described from Mexico, the species possessed a peculiar type of larval ethology as their larval bags are attached at the distal end (Sobczyk, 2021). A new species *Naevipenna mexicana* Sobczyk has been described from Mexico along with three new reports in the Oiketicinae fauna of Mexico by Sobczyk (2022). A new species of the genus *Bankesia* was reported from Italy, *Bankesia desplatsella* sp.nov. (Scalercio and Bertaccini, 2017). A new bagworm genus *Antillopsyche* and species *Antillopsyche sessilis* with unusual larval feeding behaviour were reported from Cuba and West Indies, *Antillopsyche sessilis* is showing sedentary feeding behaviour in the larval stage (Aguila and Davis, 2016). A new genus and species *Obtexocorytus schuettei* were described in Madagascar (Sobczyk, 2009 a, b).

Recently Usha *et al.* (2022c, 2023,) reported a genus and two new species of bagworm moth named *Capulopsyche*, *Capulopsyche keralensis* and *Eumasia thomasii* from Kerala, India. *E. thomasii* was the tenth species of the subfamily Eumasiinae from Asia and the third one from India. *Capulopsyche keralensis* is the first genus and species from the subfamily Taleporiinae from India. Usha *et al.* (2022 a) did a redescription and neotype of one species, *Acanthopsyche alstoni* from Kerala, which was previously known only from its larval bags collected from Assam, India (Watt & Mann, 1903).

It is evident that with advancements in scientific tools and new techniques being integrated *taxonomical* methods, many new species and new reports or range extensions are being reported all over the world. At the same time, the survey of scientific literature on bagworms shows a paucity of research data from Southern India based on comprehensive studies of bagworms. Even though bagworms have not yet become a significant pest in Kerala, there is always chance of pestilence due to poor agroforestry practices, habitat disruptions, and climate change.

2.3. Methodology

2.3.1. Study area:

The studies were conducted in randomly selected sites in Kerala (Fig.1). These sites include all types of land use except reserve forests, protected areas and monoculture plantations of Kerala Forest Development Corporation and Oil Palm Corporation.

The state of Kerala lies between the Arabian Sea and the Western Ghats and is located at the southern-most part of the Indian peninsula. It lies between 8°18' and 12°48' North and 74°52' and 72°22' East. Kerala has a coastline of 580 km, Kerala 's coastline runs for some 580 km and its width ranges between 35 to 120 km. The state has been divided into three distinct geo-climatic regions: the eastern highlands, the central midlands and the coastal lowlands. Its terrain is mostly composed of Pre-Cambrian and Pleistocene geological formations. Kerala has forty-four rivers of which three are east flowing. The Western Ghats a chain of mountains with an average height of 1,500 mASL and maximum height of 2500 mASL determines the climatic and vegetational characteristics of the state and forms a natural barrier on the state's eastern boundary. The central midlands are dominated by hills of lesser altitude (250-1000m ASL) and valleys. River estuaries, brackish water canals and lakes intersect the western most coastal plains forming an interconnected water body generally known as Kerala Backwaters. This region is densely populated and is a hub of all human activities followed by the central midlands.

Kerala has been placed in the humid equatorial tropics due to an average of 120-140 rainy days per year with rains from two monsoons and a premonsoon season. The mean annual rainfall here is 3,107 mm though the lowest mean annual rainfall is around 1,250 mm and the highest is around 5,000 mm. Daily average temperature range is between 36.7 °C and 19.8 °C. Temperature fluctuations are higher in the eastern highlands.

Government sources state that 24% of Kerala's land area is under green cover with around 9,400 km² of forests which include tropical wet evergreen, semi-evergreen forests, tropical moist and dry deciduous forests, montane subtropical and temperate (shola) forests, mangroves, and fresh water swamp forests. Kerala's agriculture is dominated by many monocultures (rubber, coconut, rice, spices) and mixed crops. Unlike other states most of Kerala is semi urbanized with residential and service

buildings in close vicinity of cultivated land. Other green spaces included homestead gardens, institutional gardens, highway, and road side green belts etc. All spaces are covered with an assortment of herbs and shrubs unless controlled by human intervention. High population density in a biodiversity hotspot has led to conservation vs development conflicts and has left the state vulnerable to many natural and human induced disasters. (*Source of facts:* <https://www.stateofkerala.in>)

2.3.2. Field survey and insect collection: Randomly selected areas were surveyed for the presence of bagworms. If bagworms were observed in a sampling unit adjoining sampling units were also searched till no presence were detected. This method was followed mainly because these moths are considered to be habitat selective with clumped distribution. Therefore, cluster sampling method was adopted for the collection.

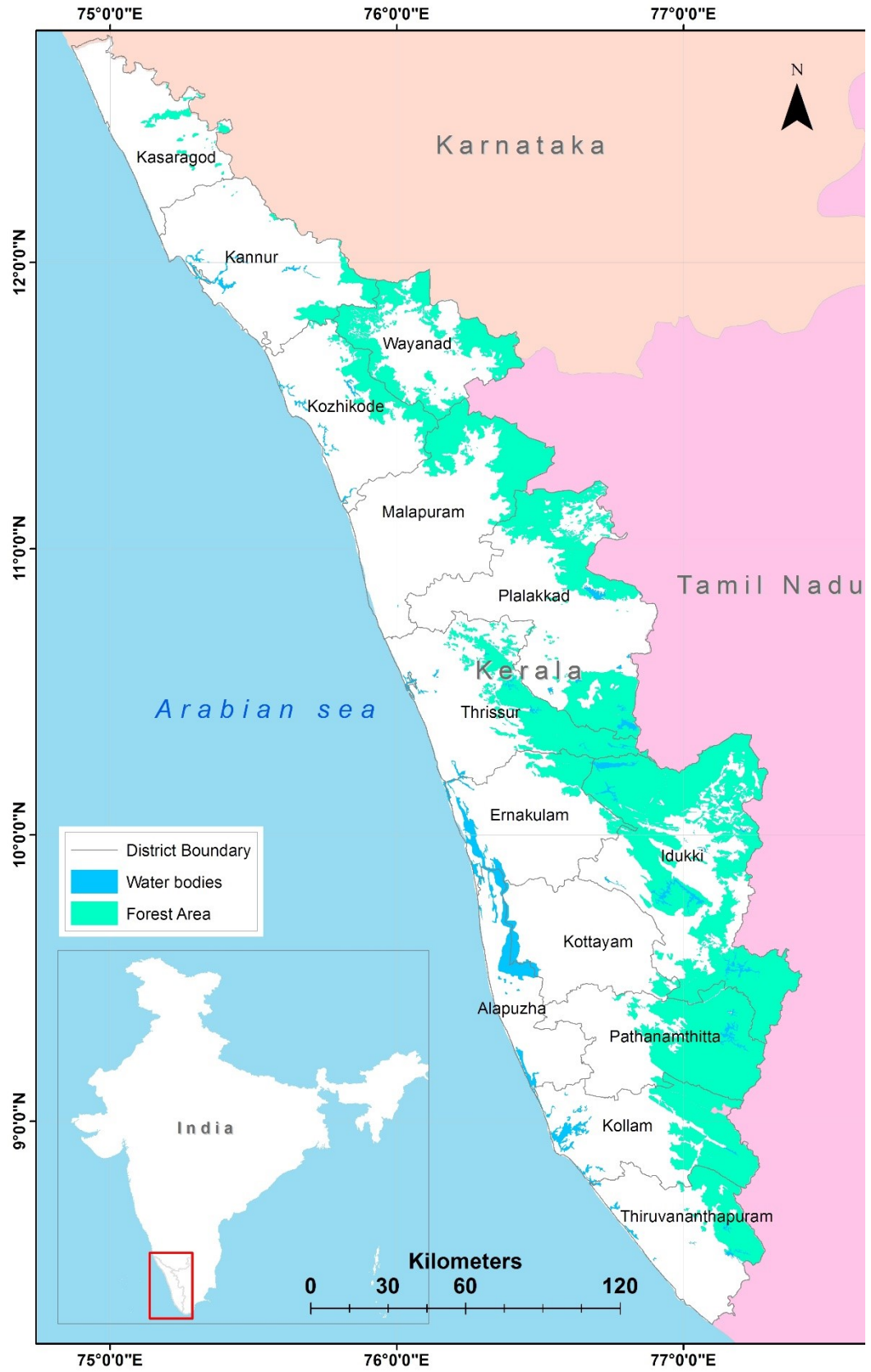


Figure 1: Map of Kerala (study area)

A total of 170 places (Appendix B) were visited from all the districts in Kerala. Forest areas were not visited. Locations with bagworms were visited more than once. Bagworms/bags were obtained from a total number of 263 site visit.

The insects were collected from human-inhabited/altered areas by direct field observations and on from plants, trees, rocks, and walls of the buildings. The bagworm bags were seen attached to the tree branches, plant twigs, leaves, barks, undersides and surfaces of rocks; concrete surfaces of buildings at various heights from the ground. The collections were made by handpicking; mainly larval and pupal bags were collected by this method (including the supporting branch/twig of host plant). The data regarding the attachment of bags on the host plant, details of the host plant, status of bags, etc and physical parameters like temperature, humidity, wind speed, geo coordinates, rainfall, etc were noted at the time of the collection. The pictures of habitat and bag attachments on plants were taken using digital cameras.

2.3.3. Bagworm rearing: Both larval and pupal bags were collected from the field and the collected bags were then transferred inside the bottles (plastic and glass) covered with a white cotton cloth and labelled according to the place from where they were from collected (Plate 2). The bags were then separated based on the species and then according to the instars and size of the larvae and relabelled.

The live larvae are reared inside the rearing bottles, provided with their respective host plant leaves and twigs. The plant materials were changed on alternative days and replaced with fresh leaves and twigs. The observations were made at continued and fixed intervals and measurements were taken.

For pupal bags, no feeding was required. So, bottles with pupal bags were kept intact without movements at room temperature. The bags were kept in the laboratory until the emergence of adults. The pupation period of each bag was noted. The adult insects (both male and female) were collected from the rearing bottles at the time of their emergence. After collecting adults, chloroform was used to sacrifice the moths in a sacrificial jar. The dead moths were spread using the spreading board and dried specimens were mounted with entomological pins and stored in insect boxes.

2.3.4. Identification

The identification of collected specimens is done by referring to the taxonomic literature (Hampson, 1892,1902,1903, Sauter and Hattenschwiler,1999, Meyrick, 1919) and consultation with the experts. Most of the characteristics are present in male

adults so adult males are used for species identification. Adult females, pupae and larval bags have less taxonomic value and are used as secondary material or as supplementary data for species description. The identity of larvae and females were confirmed only after the males emerged from the bags. The general characteristics used to identify the specimens up to species level were wingspan, wing venation, wing scales, presence of tibial epiphysis, antennal structure, and structure of genitalia of male moths. Indexes of the eye, tibia and wings are also used for accurate identification between species and in their descriptions.

2.4. Results

Twenty-six species belonging to six subfamilies of Psychidae were reported from the study area. Fourteen specimens were identified at the species level and three were identified at the genus level using the adult characteristics and COI sequencing (details given in next chapter). Nine species could not be identified till genus or species level because of the lack of male adult insects. Only larva and larval bags were available for this species. These species were classified till subfamily level using COI sequencing and bag characteristics (Table 2 and 3). The list includes the reports of one new genus and three new species and one species rediscovery and neotype designation from Kerala, India which was published in reputed journals (Usha *et al.*, 2022a, b, c, 2023).

In addition to the discoveries new to science, five species are first reports from the state of Kerala. Majority of the species were phytophagous (in this study the term has been used to indicate feeding on trees, shrubs, herbs and grasses only) but a few species fed on mosses, algae and lichens. The number of sightings and spatial distribution of this second group was restricted when compared to the first group (phytophagous) Table 3.

Table 2: Systematic position and summary of collected species

Clade	Superfamily	Family	Subfamily	Genus	Total number of species in the study area
Ditrysia Börner, 1925	Tineoidea Latreille, 1810	Psychidae Boisduval, 1829	Oiketicinae	<i>Acanthoecia</i>	2
				<i>Acanthopsyche</i>	3
				<i>Eumeta</i>	2
				<i>Manatha</i>	1
				<i>Clania</i> (incerte sedis)	1
				Unidentified sp.	7
			Metisinae	<i>Metisa</i>	2
				<i>Pteroma</i>	1
			Eumasiinae	<i>Eumasia</i>	3
			Typhoniinae	<i>Struthisca</i>	1
				<i>Degiella</i>	1
				Unidentified sp.	1
			Taleporiinae	<i>Capulopsyche</i>	1
			Unidentified	Unidentified	1

Table 3: Checklist of Psychidae recorded from the study area with additional remarks

Subfamily	Species name	Author and description year	Identification confirmed with the following characteristics	Plate No	Sighting frequency *	Remark
Oiketicinae	<i>Acanthoecia larminati</i>	Heylaerts, 1904	Larva, pupa, adult (male), bag	3	+++	First report from Kerala, Phytophagous
	<i>Acanthopsycha alstoni</i>	Watt & Mann, 1903	Larva, pupa, adult (male, female), bag	5	++	Neotype & Rediscovery after 119 years from India, Phytophagous
	<i>Acanthopsycha cana</i>	Hamson, 1892	Pupa, adult (male), bag	4	++++	First report from Kerala, Poly phytophagous
	<i>Acanthopsycha</i> sp.	Hamson, 1892	Larva, pupa, adult (male, female), bag	6	++++	Poly phytophagous
	<i>Eumeta crameri</i>	Westwood, 1854	Larva, pupa, adult, bag, COI	7	++++	Poly phytophagous
	<i>Eumeta variegata</i>	Snellen, 1879	Pupa, adult(male), bag, COI	8	+	Poly phytophagous
	<i>Manatha albipes</i>	Moore, 1877	Larva, pupa, adult (male, female), bag, COI	9	++++	Poly phytophagous
	<i>Clania holmesi</i> incertae sedis	Watt, 1898	Larva, pupa, adult (male), bag	10	+++	First report from Kerala, Poly phytophagous

Subfamily	Species name	Author and description year	Identification confirmed with the following characteristics	Plate No	Sighting frequency *	Remark
	Unidentified sp.1	-	Larva, bag, COI	25	+++	Poly phytophagous ,
	Unidentified sp.2	-	Larva, bag, COI	25	+	Phytophagous
	Unidentified sp.3	-	Larva, bag, COI	25	+	Phytophagous - Bark feeding
	Unidentified sp.4	-	Larva, bag, COI	25	++	Poly phytophagous ,
	Unidentified sp.5	-	Larva, bag, COI	25	++	Poly phytophagous ,
	Unidentified sp.6	-	Larva, bag, COI	26	++	Poly phytophagous
	Unidentified sp.7	-	Larva, bag, COI	26	++	Poly phytophagous
Metisinae	<i>Metisa plana</i>	Walker, 1883	Larva, pupa, adult (male, female), bag	12	++++	Poly phytophagous
	<i>Metisa canifrons</i>	Hampson, 1910	Larva, pupa, adult (male, female), bag	11	+++	First report from Kerala, Poly phytophagous
	<i>Pteroma plagiophleps</i>	Hampson, 1892	Larva, pupa, adult (male, female), bag	13	++++	Poly phytophagous
Typhoniinae	<i>Degiella</i> sp.nov	Sobczyk, 2009	Larva, pupa, adult (male), bag	17	++	A new report and new species from

Subfamily	Species name	Author and description year	Identification confirmed with the following characteristics	Plate No	Sighting frequency *	Remark
						India, Phytophagous
	<i>Struthisca cf farinosa</i>	Meyrick, 1919	Larva, pupa, adult (male, female), bag	18	++	A new report from Kerala, Phytophagous
	Unidentified sp. 8	-	Larva, bag, COI	26	+	Algae feeding
Eumasiinae	<i>Eumasia thomasi</i>	Usha et al., 2022	Larva, pupa, adult, bag	14, 15	+	New species from India, Algae feeding
	<i>Eumasia venefica</i>	Usha et al., 2023	Larva, pupa, adult, bag	16	+	New species from India, Lichen feeding
	<i>Eumasia sp.</i>	Chrétien, 1904	Larva, bag, COI	26	+	Lichen feeding
Taleporiina	<i>Capulopsyche keralensis</i>	Usha et al., 2023	Larva, pupa, adult, bag	19, 20	+	New genus and species from India, Algae, lichen feeding
Unknown	Unidentified sp. 9	-	Larva, bag, COI	26	+	Bark, lichen feeding

* Sighting frequency

++++= found in more than 75% of the sites visited, +++= found in 51 to 75% of the sites visited

++= found in 25 to 50 % of the sites visited, += found in less than 25% of the sites visited

2.5 Discussion

The previous studies on the diversity of moths in Kerala and India mentioned only a few numbers of Psychids (Appendix A). Bagworm moths if reported were very commonly reported species, such as *Eumeta crameri*, *Eumeta variegata*, *Pteroma plagiophleps* and *Metisa plana*. Many studies focused only on the taxonomy and pestilence of single species of bagworms, so comprehensive studies on bagworm diversity and ecology in Kerala and India is not available.

One species of bagworm *Clania holmesi* Watt, 1898 is considered *incertae sedis* because its broader relationships are still unknown or undefined. Watt in 1898, described the species only based on its larval bags and the characteristics of its adults was unknown. So, a transfer of its genus is necessary, as its adults shows dissimilarities with the genus *Clania*. This taxonomic mystery can be solved only with further studies.

Subfamily Oiketicinae is the most dominant group in the list, it has eighteen species belonging to five genera, *Acanthoecia*, *Acanthopsyche*, *Eumeta*, *Manatha*, and *Clania* (*incertae sedis*). *Acanthoecia* has one species *A. larminati*, is the first report from Kerala. *Acanthopsyche* has three species *A. cana* (first report from Kerala), *A. alstoni* and one unknown species. *A. alstoni* is redescribed after 119 years from India and designated as a neotype, which was previously known only from its larval bags.

Subfamily Metisinae has two genera, *Metisa* and *Pteroma* and have three species, *M. canifrons*, *M. plana* and *P. plagiophleps*. All these three species are poly phytophagous and reported as pest species from many places in India. *M. canifrons* is the first report from Kerala.

Subfamily Eumasiinae and Typhoniinae has three species each. Arnscheid and Weidlich defined the Eumasiinae in 2017 based on the type genus *Eumasia*. It is the monotypic genus in the subfamily (Arnscheid & Weidlich 2017). The present study recorded three species including two new species, *E. thomasi*, *E. venefica* and one unidentified species. Fourteen species of genus *Eumasia* had been described worldwide of which only two were from India. After the additions of two new species the list is revised to 16 and 04 respectively. The subfamily Typhoniinae has three species, *Struthisca cf farinosa*, and *Degiella sp.*, and one unidentified species. The species

identification of the specimens could not be done because of the lack of adult male insects.

Subfamily Taleporiinae has one new genus described, *Capulopsyche* Usha *et al.*, 2023 and species *Capulopsyche keralensis* Usha *et al.*, 2023. This genus and species are the first in the subfamily Taleporiinae to be reported from India.

The mitochondrial COI sequence analysis of all the species was done, and the subfamily-level classification of all unidentified species was completed based on this. So, one unidentified subfamily is reported based on the COI sequence and divergence in phylogeny analyses which are marked as “unknown” (Fig. 2). The species included in the unknown subfamily is also unidentified as no male adults were recovered.

Feeding habits: Most of the bagworm species are poly phytophagous. All species in the subfamily Oiketicinae were phytophagous and many of them are considered insect pests of plants causing severe damage. The predominant genera in Oiketicinae as pest are *Eumeta*, *Manatha* and *Acanthopsyche*. *Metisa* and *Pteroma* are prominent pest genera in Metisinae. There are many studies mentioning their pestilence from Kerala and India (Nair *et al.*, 1981; Varma., *et al.*, 1989; Varma, 2007; Mathew., 1989; Agrawal *et al.*, 1997; Usha *et al.*, 2021, 2022b; Poorani *et al.*, 2022). Most of the unidentified species in this subfamily voraciously feed on plants causing severe defoliation and loss of foliage in trees.

The species in the subfamily Typhoniinae are also phytophagous, feeding on plant matter but the records of damage caused to higher plants by this species are not reported. The species *Degiella sp.* and *Struthisca farinosa* cf fed on small plants like grass and lichens. The species in the genus *Eumasia* fed on algae and lichens on rock, walls and tree trunks (Saigusa and Sugimoto, 2005; Arnscheid and Weidlich, 2017). *Capulopsyche keralensis* fed on mosses, algae and other similar growths on tree barks.

The dominance in poly phytophagy (Table 3) of Psychids indicates the pestilence potential of these insects. So extensive surveys and studies are needed for their detailed distribution patterns in Kerala.

2.6 Conclusion

The study listed a total of 26 different species belonging to six subfamilies of bagworms from the study area. Of these 14 species were identified up to the species level, three up to the genus level and nine species are undetermined. The list includes the reports of one genus and three species new to science and one species rediscovery and neotype designation from Kerala, India.

The subfamily-level classification of unidentified and identified species was done by phylogeny analysis of COI sequences of the species and other taxonomic tools (See Chapter 3) indicated six different subfamilies including one unknown subfamily. Systematics of Psychidae in the study area needs further investigations to ensure taxonomic revision of many taxa and description of taxa new to science.

PLATE 1

Insect collection



Figure a: Location: Kodumbu, Palakkad



Figure b: Location: Melaranoor,
Thiruvananthapuram



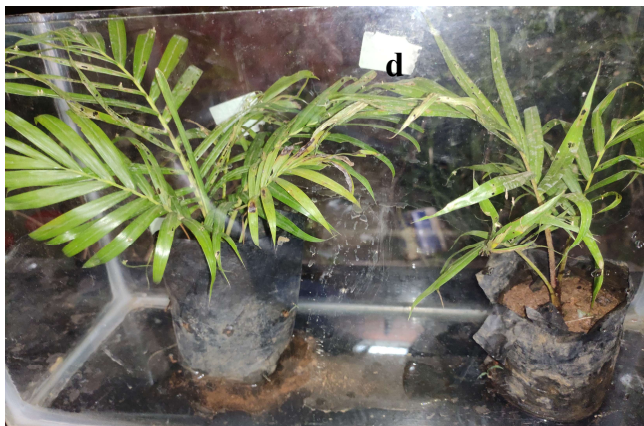
Figure c: Location: Pullu, Thrissur



Figure d: Location: Pariyaram, Kannur

PLATE 2

Bagworm rearing



Figures: **a.** Rearing of *Eumeta crameri* in plastic bottles, **b.** Larvae of *Manatha albipes* on *Syzygium samarangense* plant, **c.** Rearing of *Eumeta crameri* in glass chamber, **d.** Rearing of *Metisa plana* on *Dypsis lutescens* samplings **e.** Rearing of *Eumeta crameri* on a live plant of *Phyllanthus emblica*

CHAPTER 3

Taxonomy of Psychidae from human- altered non-forested regions of Kerala

CHAPTER 3

Taxonomy of Psychidae from human-altered non-forested regions of Kerala

3.1 Introduction and Review of Literature

Moths are the most ecologically and taxonomically diverse group of insects (Wagner *et al.* 2021). More than 90% of Lepidopterans are thought to be moths, while many of them are still unknown (Joshi *et al.*, 2021). Identification of Microlepidoptera is difficult because of their small size, irregular habits and cryptic morphological traits. Due to its distinct biology and significant adult sexual dimorphism, the family Psychidae presents an even harder challenge. It is estimated that there are more than 1450 described species of Psychidae from all over the world belonging to 10 subfamilies and 241 genera (Sobczyk, 2011, 2019, Nieukerken *et al.*, 2011). Most of the taxonomic work on this taxon at a global level has been discussed in the previous chapter.

From India Hampson (1892) listed 36 species from British India including Sri Lanka and Myanmar. More recently 106 species belonging to 34 genera have been reported from India (Sobczyk, 2011; Shah *et al.*, 2017). A recently published report consolidated twelve species from eleven genera of Psychidae from the north-east biogeographic zones of India based on previously published works (Joshi *et al.*, 2021). From Kerala, many studies (Ayyar 1940; Nair 1978; Nair *et al.*, 1981; Mathew and Nair 1983, 1986; Nair and Mathew, 1992; Pillai and Gopi, 1990) on bagworms moth mainly focused on the taxonomic descriptions and pestilence of the individual species.

Understanding the systematics of bagworms is important because several species are pests of cultivated crops (Rhainds *et al.*, 2009). In this context, a detailed description of the adults, larvae and pupal exuvia of all Psychidae identified till species level from the study area is presented here.

3.2 Methodology

3.2.1. Study area was human habitations or human-altered non-forested areas of Kerala state India (Fig. 1) and has been described in detail in the previous chapter (2.3). Methods followed for collection and rearing have also been discussed in detail (2.3).

3.2.2. Morphology of adult, larva and pupa for identification of the species

3.2.1.1. Morphology of adult: Adult males were collected from rearing bottles after emergence. They were sacrificed by placing them in a jar with cotton soaked in chloroform. The dead moths were then spread using spreading boards, dried and preserved in insect boxes. The morphology of moths was studied by preparing microscopic slides of different parts (wings, legs, antennae and genitalia) (Robinson, 1976; Kunte, 2000). The photographs of specimens and measurements were taken using DFC450 camera of Leica M205C stereomicroscope and Leica S8APO stereomicroscope.

3.2.1.2. Morphology of larvae: The larval morphology was studied for all species, except for some species whose larval stages could not be collected. External morphological characters (colour, size, shape, prolegs, arrangement of setae) the total length, head capsule width and the number of segments were noted. Mainly the larvae of the last instar stage were used for the study.

3.2.1.3. Morphology of pupal exuvia: The pupal exuviae of male and female adults were collected from the bags at the time of hatching. Most female adults pupated inside the bags and remained inside the bag until their death (Saigusa 1962; Rhainds, *et al.*, 2009). So, the pupal skeleton was missing or difficult to find. The female of some subfamilies emerged as moths (e.g. Eumasiinae and Typhoniinae) in which case the female pupal exuviae could be easily collected. The pupal stage is shorter for females than for males (Rhainds, *et al.*, 2009). The external characteristics of pupal exuviae, such as colour, shape, length, width, diameter and arrangement of spines were noted. The measurements were taken by using measuring scales and a DFC450 camera of Leica M205C stereomicroscope and Leica S8APO stereomicroscope.

3.2.3. Procedure of slide preparation of wings (Kunte 2000):

Equipment required: Stereo microscope, fine forceps, needles, brushes, excavated glass blocks, glass slides and cover slips.

Chemicals required: Glacial acetic acid, absolute alcohol, purified or distilled water, fuchsin stain powder, Canada balsam, xylene.

The slides of wings were prepared by the following steps (Kunte, 2000)

- I. Wings from one side of moths was detached from the thorax carefully by using a micro-needle and forceps.

- II. The detached wings were then placed in a watch glass containing a little alcohol, acetic acid, or even plain water.
- III. Then it was gently pressed for the removing scales by using a paper-pencil or brush.
- IV. Paper pencil is made by rolling a piece of paper.
- V. After descaling, the wings were used for slide preparation.
- VI. For mounting, the descaled wings were washed in water and stained with acid – Fuschin stain. (Acid – Fuchsin stain powder 5 mg is dissolved in 100 ml of acetic acid).
- VII. The stained wings were transferred to the xylene solution for clearing.
- VIII. After clearing the wings were transferred to a slide having a drop of Canada – balsam and covered by coverslips.
- IX. The prepared slides were then properly labelled and photographed by using a Leica stereo microscope S8APO and the structure was studied.

3.2.4. Procedure of slide preparation of genitalia (Robinson 1976)

Equipment required: Leica stereo microscope, fine forceps, needles, brushes, excavated glass blocks, petri dish, glass slides and cover slips,

Chemicals required: Potassium hydroxide solution (10% KOH), absolute alcohol, purified or distilled water, Canada balsam.

The following steps were used to prepare moth genitalia:

- I. Remove the abdomen by using forceps and place it in 10% KOH solution overnight or by gently heating it with the solution.
- II. Remove the abdomen to a petri dish with a small amount of water
- III. Gently remove scales with needles and a soft hair brush. Stain if required, also to wash off excess stains in water.
- IV. If it is a male, tease out the genital capsule.
- V. If it is a female, gently cut away the abdominal skin.
- VI. Place genitalia in ethyl alcohol to dehydrate. Do not leave for too long.

VII. After clearing the genitalia was transferred to a slide having a drop of Canada – balsam and covered by coverslips.

VIII. The prepared slides were properly labelled by its specimen number and the correct description about the specimen.

IX. The prepared slides were then photographed by using Leica stereo microscope S8APO and the structure was described.

3.2.5. Identification and classification: The identification of species was done by using the adult male insects as per ICZN regulations which state that descriptions and identifications should be based on adult descriptions. The following characters were observed for identification (Tables 4& 5).

Table 4. List of adult male moth characteristics used for identification

No	Body part	Characteristics	Source
1	Wings	Wingspan Forewing venation – number of veins, number of dc veins Hindwing venation – number of veins, number of dc veins Scales – colour and shape of wing scales	Hampson, 1892 Meyrick, 1919 Hättenschwiler 1998 Saigusa & Sugimoto, 2005
2	Antenna	Structure of antenna Number of segments	Hättenschwiler 1998 Hampson, 1892
3	Legs	Epiphysis on tibia – presence or absence Shape of epiphysis	Hampson, 1892
4	Genitalia	Shape of aedeagus and phallus	Sauter (1956).

The identification of species was done from the literature (Hampson,1892; Hampson, 1900; Meyrick,1919; Watt & Mann,1903; Saigusa, 1962; Sauter & Hättenschwiler, 1991; Sugimoto, 2009; Sobczyk, 2011; Saigusa and Sugimoto, 2013; Roh and Byun, 2016) and referring to, Dr. Thomas Sobczyk, (Diesterwegstraße 28, D-02977 Hoyerswerda, Germany) and Dr. Wilfried R Arnscheid, (Im Ostholz 58, D-44879 Bochum, Germany) the world experts of Psychidae who confirmed the identification of the species by referring the macro and micro photographs.

Table 5. List of larval, bag and female moth characteristics used for supporting identification

No	State	Characteristics	Citation
1	Bag	Shape, bag-making material, attachment,	Sugimoto, 2009 a,b
2	Female adult	Type of female sexual dimorphism	Saigusa, 1962
3	Larva	Larval habitat	Watt & Mann (1903) Saigusa and Sugimoto 2013 Roh and Byun 2016

3.2.6. COI Sequencing and phylogeny analysis

3.2.6.a Methodology of COI sequencing

Genomic DNA Isolation: Tissues from the larvae and moths were used for the genomic DNA extraction. Sequencing of the Mitochondrial cytochrome oxidase 1 gene was done for all the species. The DNA extraction and sequencing were done at Rajiv Gandhi Centre for Biotechnology, Thiruvananthapuram (RGCB).

Genomic DNA was isolated using NucleoSpin® Tissue Kit (Macherey-Nagel). The steps are following, A small tissue (~20 mg) was taken in a microcentrifuge tube. 180 µl of T1 buffer and 25 µl of proteinase K was added and incubated at 56 °C in a water bath until it was completely lysed. After lysis, 5 µl of RNase A (100 mg/ml) was added and incubated at room temperature for 5 minutes. 200 µl of B3 buffer was added and

incubated at 70°C for 10 minutes. 210 µl of 100% ethanol was added and mixed thoroughly by vortexing. The mixture was pipetted into NucleoSpin® Tissue column placed in a 2 ml collection tube and centrifuged at 11000 x g for 1 minute. The NucleoSpin® Tissue column was transferred to a new 2 ml tube and washed with 500 µl of BW buffer. The wash step was repeated using 600 µl of B5 buffer. After washing the NucleoSpin® Tissue column was placed in a clean 1.5 ml tube and DNA was eluted out using 50 µl of BE buffer.

Agarose Gel Electrophoresis: The quality of DNA isolated was checked by using Agarose gel electrophoresis. 1µl of 6X gel-loading buffer (0.25% bromophenol blue, 30% sucrose in TE buffer pH-8.0) was added to 5µl of DNA. The samples were loaded to 0.8% agarose gel prepared in 0.5X TBE (Tris-Borate-EDTA) buffer containing 0.5 µg/ml ethidium bromide. Electrophoresis was performed with 0.5X TBE as electrophoresis buffer at 75 V until the bromophenol dye front migrated to the bottom of the gel. The gels were visualized in a UV transilluminator (Genei) and the image was captured under UV light using a Gel documentation system (Bio-Rad).

PCR Analysis: PCR amplification reactions were carried out in a 20 µl reaction volume which contained 1X Phire PCR buffer (contains 1.5 mM MgCl₂), 0.2mM each dNTPs (dATP, dGTP, dCTP and dTTP), 1 µl DNA, 0.2 µl Phire Hotstart II DNA polymerase enzyme, 0.1 mg/ml BSA and 3% DMSO, 0.5M Betaine, 5 pM of forward and reverse primers (Table 6).

Table 6: The list of primers used in the PCR amplification

Target	Primer Name	Direction	Sequence (5' → 3')	References
COI	LCO	Forward	GGTCAACAAATCATAAAGATATTGG	Folmer <i>et al.</i> , 1994
	HCO	Reverse	TAAACTTCAGGGTGACCAAAAAATCA	

PCR amplification profile for mitochondrial COI gene: PCR thermal cycler (GeneAmp PCR System 9700, Applied Biosystems) was used for the PCR amplification. The number of cycles in each temperature setting and time of PCR

amplification are following:

98 °C (30 sec)

98 °C (5 sec), 45 °C (10 sec) and 72 °C (15 sec) for 10 cycles

98 °C (5 sec), 50 °C (10 sec) and 72 °C (15 sec) for 30 cycles

72 °C (60 sec)

4 °C (∞)

Agarose Gel electrophoresis of PCR products: The PCR products were checked in 1.2% agarose gels prepared in 0.5X TBE buffer containing 0.5 µg/ml ethidium bromide. One µl of 6X loading dye was mixed with 5 µl of PCR products and was loaded and electrophoresis was performed at 75V power supply with 0.5X TBE as electrophoresis buffer for about 1-2 hours, until the bromophenol blue front had migrated to almost the bottom of the gel. The molecular standard used was a 2-log DNA ladder (NEB). The gels were visualized in a UV transilluminator (Genei) and the image was captured under UV light using Gel documentation system (Bio-Rad).

ExoSAP-IT Treatment: ExoSAP-IT (GE Healthcare) consists of two hydrolytic enzymes, Exonuclease I and Shrimp Alkaline Phosphatase (SAP), in a specially formulated buffer for the removal of unwanted primers and dNTPs from a PCR product mixture with no interference in downstream applications. Five micro litres of PCR product are mixed with 2 µl of ExoSAP-IT and incubated at 37°C for 15 minutes followed by enzyme inactivation at 80°C for 15 minutes.

Sequencing using BigDye Terminator v3.1: Sequencing reaction was done in a PCR thermal cycler (GeneAmp PCR System 9700, Applied Biosystems) using the BigDye Terminator v3.1 Cycle sequencing Kit (Applied Biosystems, USA) following manufactures protocol.

PCR Product (ExoSAP treated) 10-20 ng, Primer 3.2 pM (either Forward or Reverse), Sequencing Mix 0.28 µl, Reaction buffer 1.86 µl, Sterile distilled water makeup to 10µl are the components of PCR mix. The temperature settings were, 1st cycle at 96°C for 2 minutes followed by 30 cycles at 96°C for 30 sec, 50°C for 40 sec and 60°C for 4 minutes.

Sequence Analysis: The post sequencing PCR clean up were done and the product was sequenced in ABI 3500 DNA Analyzer (Applied Biosystems). Sequence Scanner Software v1 (Applied Biosystems) and Geneious Pro v5.1 (Drummond *et al.*, 2010)

were used for the sequence quality check and sequence alignment, required editing of the obtained sequences respectively.

3.2.6.b Phylogenetic analysis

The COI sequences of species identified up to species level were submitted to NCBI GenBank and accession numbers were acquired. The sequence identity was checked using NCBI-BLAST software and the phylogeny analysis of all COI sequences was done using the software MEGA11(Tamura *et al.*, 2021). The evolutionary history was inferred using the Neighbor-Joining method (Saitou and Nei,1987). The bootstrap consensus tree inferred from 300 replicates is taken to represent the evolutionary history of the taxa analyzed (Felsenstein, 1985). Branches corresponding to partitions reproduced in less than 50% of bootstrap replicates are collapsed. The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (300 replicates) are shown next to the branches (Felsenstein, 1985). The evolutionary distances were computed using the Maximum Composite Likelihood method (Tamura *et al.*,2004) and are in the units of the number of base substitutions per site. This analysis involved 26 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair (pairwise deletion option). There were a total of 692 positions in the final dataset.

3.3 Results

3.3.1. Identifying characters of different taxonomic ranks

The phylum Arthropoda represents the largest group of described species in the animal kingdom. The arthropods are having many adaptations and 84% of described species in the whole animals are from this phylum. The phylum has key features like:

- Segmented body and jointed appendages: legs, antenna
- Bilateral symmetry
- Presence of joined exoskeleton made up of chitin

The phylum Arthropoda divides into four subphyla: Chelicerata (arachnids), Crustacea (crustaceans), Hexapoda (insects and springtails) and Myriapoda (millipedes and centipedes). The insects come under the subphylum Hexapoda and Class Insecta, the key features to class Insecta are:

- Six segments fused from the head
- Trunk divides into thorax and abdomen
- Presence of ocelli and compound eyes

The subphylum Hexapoda (*Insecta sensu lato*) is taxonomically classified into two major classes: Entognatha and Ectognatha (*Insecta sensu stricto*) (Hennig *et al.*, 1953).

Order Lepidoptera (Linnaeus, 1758) includes moths and butterflies with four suborders, 46 superfamilies, 126 families, 15578 genera and 157424 species described worldwide (Nieukerken *et al.*, 2011).

The key features of the order Lepidoptera are;

- Presence of scales on wings and body, the word Lepidoptera derived from this characteristic feature.
- They undergo complete metamorphosis (holometabolous).
- Pupa is known as a chrysalis

Order Lepidoptera is classified into two, based on the structure of the antenna, **Heterocera** and Rhopalocera. Moths come under Heterocera, which have varied or feathery and thread-like antennae. Butterflies are included in the Rhopalocera, which possess ‘club-antenna.’

Family Psychidae (Boisduval, 1829) is one of the families coming under the Ditrysian superfamily Tineoidea. Psychids are commonly known as bagworms, bagworm moths and bagmoths. They make larval bags around their body by using different materials from plants, algae, etc. Ten subfamilies, 241 genera and 1450 species are described worldwide (Sobczyk, 2011, 2019, Nieukerken *et al.*, 2011).

The key features of this family are:

- Building bags/cases in their larval stage
- Small to medium-sized moths
- Wingspan ranges 4 to 28 mm length
- Adult females are either completely winged (e.g., Eumasiinae, Typhoniinae), brachypterous, apterous (e.g., Taleporiinae), or vermiform (Oiketicinae, Metisinae)

- Males are usually fully winged

Family Psychidae is classified into different subfamilies mainly based on the wing scales pattern, wing venation, antennal structure, genital structure, the structure of legs and type of sexual dimorphism. The four subfamilies of family Psychidae recorded in this study are detailed below.

Subfamily: Oiketicinae Herrich-Schäffer, 1855

- Mostly large, strong moths
- Antenna about reaching about half forewing length (excl. the east Palearctic genera *Manatha* and *Mahasenà*).
- Hind veins m2 and m3 arise with a short stalk, from a point or are slightly separated and diverge towards the apex.
- Bipectinate antenna in males.
- Long tibial epiphysis present in the foreleg.
- Males are moths and females are vermiform without any appendages.

Subfamily: Metisinae Sauter & Hättenschwiler, 1999

- Very delicate, mostly small moths.
- Antenna about one-third of forewing length.
- Hind wing veins m2 and m3 arise separately and remain parallel to the apex or unite before reaching the apex.
- Foreleg tibia with long epiphysis.
- Bipectinate antenna in males.
- Males are moths and females are vermiform without any appendages.
- Pupal bags hanging on a thread.

Subfamily: Eumasiinae Arnscheid & Weidlich 2017

- Wings are developed in both sexes.
- Antennae filiform and each segment of male antennae covered with short cilia and middle segment with dorsally fanned scales.
- Forewing lanceolate and narrow with mostly seven veins arising from dc.

- Sacculus of male genitalia blunt, annellus lacked and the juxta-like wide plate.
- This subfamily has monotypic genus – *Eumasia*.

Subfamily: Typhoniinae Lederer, 1852

- The subfamily is characterized by winged adults in both sexes.
- The males have pectinate antennae.
- The females have threadlike antennae.

Subfamily Taleporiinae Herrich-Schäffer, 1857

- Males are winged moths.
- Females are wingless, with legs and short antennae.
- Male antenna thread-like/filiform.

3.3.2. Taxonomic key to the 5 subfamilies and 10 identified genera of Psychidae moths from Kerala

Building bags/cases in their larval stage, Small to medium-sized moths, males are usually fully winged; wingspan ranges 4 to 40 mm length.....**Psychidae**

3.3.2.1. Taxonomic key

1. Adult females are vermiform.....2
- 1'. Adult females are not vermiform.....7
2. Hind veins m2 and m3 arise with a short stalk, from a point or are slightly separated and diverge towards the apex.(**Oiketicinae**)3
- 2'. Hind wing veins m2 and m3 arise separately and remain parallel to the apex or unite before reaching the apex.....(**Metisinae**).....6
3. Ten veins from dc forewing.....4
- 3'. Nine veins from dc in the forewing.....*Acanthopsyche*
4. six veins from the dc hindwing.....5
- 4'. five veins from the dc hindwing..... *Acanthoecia*

5. Vinculum broad and V-shaped, saccus with pointed apex *Eumeta*
- Vinculum narrow and V-shaped, saccus with pointed apex *Manatha*
6. Ten veins from the dc forewing, seven veins from the dc hindwing *Metisa*
- 6'. Eight veins from the dc forewing, six veins from the dc hindwing *Pteroma*
7. Adult females are completely winged.....8
- 7'. Adult females are not completely winged(brachypterous or apterous)
- (*Taleporiinae*)10
8. Forewing lanceolate and narrow.....(*Eumasiinae*)... *Eumasia*
- 8'. Forewing broad and oval/ round shaped *Typhoniinae*9
9. Ten veins in the forewing, six veins from the dc hindwing..... *Degiella*
- 9'. Eleven veins in the forewing, five veins from dc hind wing.....*Struthisca*
10. Nine dc-veins in the forewing and five dc-veins in the hind wing....*Capulopsyche*
- 10'. Does not have Nine dc-veins in the forewing and five dc-veins in the hind wing.....Any other genus from *Taleporiinae**

**Capulopsyche* is first moth from Subfamily *Taleporiinae* reported from India. It is a newly discovered genus. It was distinguished from all other *Taleporiinae* worldwide based on its typical wing venation.

3.3.3. Taxonomic descriptions of the identified species of Psychidae

Subfamily Oiketicinae Herrich-Schäffer, 1855

3.3.3.a *Acanthoecia larminati* Heylaerts, 1904

(Plate 3, Figures. a-h)

Materials examined: 02, 10.5081° N 76.2515° E, 10.3942° N 76.1410°, Usha A U, Hostplant: Nil

Adult moth: Small, blackish moth, wingspan 12 mm, ground colour of wings white, forewing covered with thick black scales, hindwings are almost transparent and covered with white hair-like scales. The head, vertex, frons and underside of the eyes are

covered with whitish hairs, ocular index 1.19 mm. The body of the moth is 4.3 mm long. Thorax blackish, thinly covered with shiny whitish hairs, length 1.2 mm. The coxa and tibia of legs are blackish brown with long whitish hairs, tarsal segments light brown with short whitish hairs, foreleg with long epiphysis along with the length of tibia. Antenna bipectinate.

Forewing length 5.6mm, forewing width 2.5 mm, forewing index 2.2 mm. The abdomen long, 2.6 mm, blackish brown, ventral side of the abdomen is densely covered with white hairs.

Wing venation: Forewing with 12 veins present, 10 veins from dc. R1 is short from dc merged with Sc at the costal margin. Except for vein R1 all other R veins originate from the same point on the anterior apex of dc. R5 is stalked with R3 and R4 by a single vein which is again branched to form R3 and R4 veins. M1 from the middle of the anterior dc, M2 and M3 stalked from the posterior apex of dc. CuA1 and CuA2 run parallel to the distal end. Anal veins are combined to form A1+2. Hindwing with 7 veins, 5 veins from dc. veins M2+M3 and CuA1 originate closely from dc to termen. Anal veins free.

Genitalia male: Long tube-like structure, length 0.5mm. Tegumen arch-shaped, valvae short and symmetrical, length 0.17 mm. Vinculum U-shaped and saccus broad at the apex. Phallus long tubular with 0.4mm length.

Pupal exuvia male: Light brownish, length 5 mm.

Larva: Body yellowish white, head highly sclerotized, head capsule whitish with light brown patches. Short hairs present on epicranium and frons regions. Thoracic legs well developed, whitish and light brown colour at the tip. The length of mature larvae 5- 6 mm.

Female: Adults show sexual dimorphism. Females vermiform without any appendages.

3.3.3.b *Acanthopsyche alstoni* Watt & Mann, 1903

(Plate 5, Figures. a-h)

Materials examined: 04, 10.9142° N 76.2118° E, 9.8584° N 76.9528° E, Usha A U,
Hostplant: *Ficus benjamina*

Moth: Small moth, brownish-black and thick-scaled wings. Body length 2.5–3mm. Wingspan 7.4 mm, forewing length 3.5 mm, forewing width 1.8 mm, forewing index 1.9 mm. Head covered densely with long brownish scales. Eyes medium-sized, black, interocular index 1.4 mm. Labial palpi fused. Tentorial pits and tentorium clearly pronounced. Antennae 12 segments, antennae length 1.35mm. Segments bipectinated, size towards apex uniformly decreasing, with cilia on both sides. Third and fourth antennal segments reaching maximum length. Scapus thickened, pedicellus disc-shaped. Forelegs covered with brownish hairs and tibia with epiphysis (EPI: 0.64mm). The distal tarsal segment is slightly longer than other tarsal segments. Thorax measures 1.1mm and with long brownish hairs. The abdomen long 1.4 mm, covered with brown hair-like scales. Dorsal side of wings are thick scaled brownish black, without a pattern, the underside of both wings with brownish scales.

Wing venation: Nine veins from dc forewing. In dc media stem undivided, dividing the cell into a larger anterior part and a small posterior part, without an accessory cell. Sc runs parallel to the R veins to the apex. Median stem run in outer margin dc between M1 and M2. From dc edge R3+R4 to one half stalked, with R2 short-stalked or from a point. The three M-veins free. Two Cu veins present and originate distally from dc. The basal fork of anal veins A1 and A2 prominent. Hind wings with five veins from dc, of this M2+M3 distally expanded. Median stem undivided. Sc free ends in front of apex at anterior margin. R1 at half its length with connecting bridge to dc. Anal veins free.

Genitalia: Elongated, 0.52 mm long, 0.28 mm with high fixed valvae. When closed, the valva does not protrude beyond the tegumen. Tegumen indented distally. Valva elongated tapering distally and present long hairs on the apex. Saccus curved, distally covered with strong spines. Vinculum near the valva widest, evenly sclerotized, saccus distally very wide, slightly rounded. Phallus straight, shorter than genital length (0.31 mm), tapering distally. The presence of gnathos is not confirmed as they are invisible in the structure.

Pupal exuvia (male): The pupal exuvia of males dark golden-brown colour and measures about 3mm in length.

Female: yellow, maggot shaped, with no wings and appendages. Length 3.8mm. The head clearly regressed, without any appendages. Sclerotization observed on the head

and thorax region and with dark brown in colour. Abdominal region poorly sclerotized and packed with eggs.

Larvae move actively on hard objects like walls, gate and concrete surfaces. The body of the larvae is light greyish colour and the head is highly sclerotized. The head capsule of the larvae is light yellowish with dark black patches on it. The length of mature larvae is about 3–3.5 mm.

3.3.3.c *Acanthopsyche cana* Hampson, 1892

(Plate 4, Figures. a-g)

Materials examined: 01, 8.8731° N 76.8694° E, Usha A U, Host plant: Nil

Adult moth: Medium-sized blackish insects, wings uniformly covered with dark brown scales, wingspan 18 mm. head, thorax and abdomen are thickly covered with pale golden-brown hairs and the ventral side of the abdomen thickly covered with dark golden-brown hairs. Labial palpi fused. Tentorial pits and tentorium clearly pronounced. The forewing covered with two types of scales, broad and hair-like. Forewing length 8.2 mm, forewing width 4.6 mm, forewing index 1.7 mm. Antenna bipectinate, 25-30 segments, length of antennal segments from middle to apex uniformly decreasing. Eyes large.

Legs brownish with long brownish-black hairs in the femur and tibia regions. Foreleg has a long epiphysis along with the length of the tibia, the tibial length 1.35 mm, the epiphysis is 1.25 mm long, EI 0.92 mm.

Wing venation: Forewing with 11 veins, 9 veins from dc, the dc divided into two equal halves in middle, five veins originate from the anterior half and four veins from the posterior half. The vein Sc runs adjacent to R1 and both merges at the costa margin. The veins R3, R4, R5 and M1 originate from the same point, stalked from the anterior apex of dc. M1 originates from the stalked vein of R3 and R4+R5 as a single branch. Veins M2 and M3 originate from the same point on the posterior apex of dc. Anal veins 2 and 3 are anastomosing.

Hindwings with 7 veins, 5 veins from dc. Vein M1 and M2+M3 are stalked, originating from the same point on dc. CuA1 and CuA2 are short and parallel. Anal veins are free.

Genitalia male: Elongated, broad, 1.48 mm long, tegumen more pointed in apex, small flap-like structures on both sides. Valvae are long and symmetrical, length 0.53 mm with long hairs and strong spines in the apex, the hairs are protruding outside the genital structure while closed. Vinculum is broad and thick anteriorly. Y-shaped, narrow anterior portion forming the saccus. Saccus very long and blunt at the end. Phallus long and broad, 1.15 mm length, and the tip of the phallus is slightly bent, wide and cup-shaped.

Female: Adults show sexual dimorphism, females are wingless insects, the body is long and cylindrical, maggot shaped without any appendages and pale yellow-coloured long body filled with eggs.

Pupal exuvia male: Dark brown colour. length 9.1 mm.

3.3.3.d *Acanthopsyche* sp. Hampson, 1892

(Plate 6, Figures. a-g)

Materials examined: 02, 11.2352° N 75.7938° E, 10.6645° N 76.2515° E, 18/02/19, Usha A U

Hostplant: *Phyllanthus reticulatus* Poir, *Phyllanthus myrtifolius*

Adult moth: Medium-sized, dark brown colour insect, body sparsely covered with brown colour hairs, wing expanse 19 mm, length of moth 8 mm. Both wings are covered with blackish-brown scales, forewing length 8.23 mm, forewing width 4.8 mm, WI 1.7 mm. antenna bipectinate, with 30 segments. Legs are sparsely covered with hairs, long epiphysis is present in the forelegs along with the length of the tibia (1.34 mm), the epiphysis is 1.24 mm long, EI 0.92 mm.

Wing venation: Forewing with 11 veins, 9 veins from dc. The vein Sc short and ends on the half-length of costa margin. The dc is divided into two halves by the median stem. R3 and R4+R5 stalked, originate directly from the apex of the anterior half of dc. M1 originate from the same point on the base of R3 and R4+R5 stalked vein. M2 and M3 originate from the posterior apex of dc separately. Vein 2 and 3 are short, parallel and end on the termen. Anal veins are anastomosing. Hindwings are with 7 veins; 5 veins are from dc. Vein Sc originates closely with dc at the base. A small connecting vein from dc to the middle of vein Sc is present in the hindwing. Veins M1 and M2+M3

are stalked from the posterior apex of dc. Cubital veins are short and parallel, anal veins are free.

Genitalia: Long, broad and sclerotized structure, length 1 mm. Valva elongated, symmetrical and presence of spines on the apex, length 0.45 mm. Tegumen arch-shaped and narrower in the middle. Vinculum wide and Y-shaped, saccus very long, pointed at the tip. Phallus long and broad, apex almost round and wider than the rest of the part, length 1.05 mm.

Female: The species show sexual dimorphism. Females are apterous, vermiform-like insects; they do not leave their bags during their lifetime. They are maggot-shaped, cylindrical, pale yellow-coloured insects with sclerotized heads and pro thorax. The length of an adult female is 12 -13 mm.

Pupal exuvia male: Dark brown, length 9mm. Pupal exuvia of a female is long, cylindrical dark brown coloured and 12 mm in length.

3.3.3.e *Eumeta crameri* Westwood, 1854

(Plate 7, Figures. a-h)

Materials examined: 04, 10.7288° N, 76.6658° E, 10.7560° N 76.6769° E, 19/02/17, 21/05/2018, Usha A U, Hostplant: *Hyptis suaveolens*, *Psidium guajava*

Adult male: Medium-sized moths, wingspan 25-30 mm. Wings are somewhat transparent despite the presence of scales and major veins clearly visible. The head, thorax and abdomen are covered with light brown hairs and thorax and abdominal lengths are 4 mm and 8 mm respectively. Eyes are large. The forewings are covered with reddish brown scales with streaks of pale blackish scales between the veins. The hind wings are covered with brown scales without any patterns. The forewing length is 12.5 mm and width 6 mm, wing index 2 mm. The mean body length of the male moths is 11 mm. Antenna bipectinate, 30- 34 segmented, 6 mm in length and the length of the antennal segments of both sides decreases from the base to the apex.

Legs are pale brown with dark brown hairs covering the coxa to femur region. The forelegs with long epiphysis originate from the femur-tibial junction and run along with the length of the tibia. The first, second and third pair of legs have mean lengths of 8.5 mm, 6.6 mm and 4.5 mm respectively.

Wing venation: Twelve veins in the forewing, 10 veins from dc, veins are darker. Veins Sc and R1 run parallel to the costal margin without any connections. Forewing with vein R3 and R4, M2 and M3 are stalked and follow previous reports (Hampson, 1892). The veins R5, R3 and R4 originate from the same point on the apex of dc. The median stem of dc divides into two branches from the middle and ends separately at the anterior margin of dc. The Cu1 and Cu2 are almost parallel to termen.

Total seven veins in the hind wing, the veins Sc+R1 and Rs are connected with one short cross vein after the position of dc. The veins M2 and M3 are stalked, dc closed with median stem. Veins CuA1 and CuA2 are parallel, anal veins are free.

Genitalia: Long tube-like, measures 3mm. The external genitalia consist of the tip of the aedeagus and valve, which protrude outside from the last abdominal segment. Tegumen is broad and convex shaped. Valvae are symmetrical, broad, with short spine-like hairs at apex. Vinculum tapering posteriorly, saccus pointed at apex. Aedeagus is a long tube-like structure with a cup-shaped anterior end, length of 2mm.

Pupal exuvia male: Golden brown colour, length 12.3 mm, circumference 9.4mm and diameter 3mm.

Adult female: Cylindrical in shape with the appearance of an egg sac, length 8 mm. Head reduced, weakly sclerotized and mouthparts and any other appendages absent. Eyes are appearing as black spots. The thorax and abdomen filled with pale yellow-coloured eggs inside a transparent body cover, vermiform in appearance. The last two segments are tapering to form ovipositor, fine hairs present around the structure.

Larvae: Pale buff coloured at the time of hatching and progressively darkens to dark brown or black as it grows. In the head, dark-coloured patches on a pale yellow colour background are present in the instars. The mean length of the newly hatched larvae was 1mm. Larvae renovated and increased its bag size by using the longest sticks at each progressing instar as described in earlier works (Agrawal and Pati, 1995, 2003).

3.3.3.f *Eumeta variegata* Snellen, 1879

(Plate 8, Figures. a-g)

Materials examined: 02, 11.2587° N 75.7803° E, 12.1197° N 75.3189° E, Usha A U,
Hostplant: *Phyllanthus emblica*, *Casuarina equisetifolia*

Adult male: When compared with the others, this is the largest species of moth collected from the study area, wingspan 35-40 mm. Forewing length 17 mm, width 7.5 mm and FI 2.2 mm. They have long abdomen and stout bodies; they fly very strongly after the emergence from the bags. The total length of an adult male moth is 21 mm, head and thorax 7 mm, the abdomen is very long almost 13 mm. Light brownish hairs on the head and lateral sides of the body. Wings are longer, the apex is pointed and the streaks of pale and dark brown scales are arranged in the interspaces of veins as described by Hampson (1892).

The vertex of the head is covered with long brownish hairs. Eyes large, black. Labial palpi fused. Tentorial pits and tentorium are clearly pronounced. Antennae 40 segments, segments bipectinated, to apex uniformly decreasing, with cilia on both sides. Scapus thickened, pedicellus disc-shaped.

Thorax: Wings are scaled with black and brownish scales with a pattern, underside of both wings is with brownish scales. Forelegs are sparsely covered with brownish hairs

and tibia with long and stout epiphysis. Both the edges of the epiphysis with fine hairs, Thorax measures 6 mm and with short light brownish hairs.

Abdomen: Very long 13.3 mm, covered with light brownish hairs. The external view of genitalia gives the appearance of cup-shaped tip of the aedeagus. Valva is elongated. When closed, the valva does not protrude beyond the tegumen.

Wing venation: Forewing with 12 veins, 10 veins from dc. The median stem of the dc is divided into two branches from the middle and runs parallelly to the apex of dc. Veins R3, R4 and R5 originate from the same point, stalked from the apex of dc, R3 and R4 stalked. R5 and M1 are almost parallel to termen. M2 and M3 stalked from posterior apex of dc. Anal veins form a 1+2 pattern.

Hindwings with 8 veins, 6 veins from dc. Median stem of dc divides into two branches and forms an accessory cell. Veins M2 and M3 are shortly stalked from the posterior apex of dc. Anal veins are free.

Pupal exuvia (male): The pupal exuvia of males is dark brown in colour and measures about 15 mm in length.

Female: The species shows sexual dimorphism in the adult stage, the females are vermiform and without any appendages.

3.3.3.g *Manatha albipes* Moore, 1877

(Plate 9, Figures. a-h)

Materials examined: 06, 10.4751° N 76.3345° E, 10.3149° N 76.1313° E, 28/05/17, Usha A U

Hostplant: *Pongamia pinnata*, *Cassia fistula*

The adult male moths were medium-sized, narrow-bodied insects with uniform brownish wings. Wingspan 18-20 mm. Forewing length 8.5 mm, forewing index 0.55, antennae bipectinate, 20 segments, ventrally with long cilia, length 2.8 mm and covered dorsally with small, thin brownish scales. The sixth and seventh antennal segments reaching maximum length. Length to apex uniformly decreasing. Scapus thickened, pedicellus disc-shaped.

Head covered densely with hair-like brown scales. Eyes are small and brown. Labial palpi fused. Tentorial pits and tentorium are pronounced. Mouthparts are reduced. Legs

are elongated, brown and femur and tibia are covered with brown scales. Tibia in the forelegs with long epiphysis. Tarsal segments are pure white.

Thorax is brown-scaled. Wings brown, without a discernable pattern. Adults show sexual dimorphism.

Wing venation: Twelve veins in forewing, ten whitish veins from dc, R3+R4+R5 stalked and from outer corner dc, M2+M3 short-stalked at the half; dc with a median stem. From A1+A2 no branch to posterior margin. Hindwings with six veins from dc, M2, and M3 separate; dc in this part extended to the outer margin. Median stem undivided in dc. Sc and Rr merged at basis.

Genitalia: Stretched, 1.5 mm long, with high fixed valvae. Tegumen is distally narrower, with two lobes. Valva anterior edge with short bristles distally rounded. The median base of the valva is connected by slender sclerotized bands. Anellus is short distally rounded, with a field of bristles. Sacculus straight and curved. Distally with six curved thorns. Saccus evenly narrowed, distally rounded. Phallus 1 mm, strong, only slightly curved, distally significantly bulged.

Pupal exuvia (male): Length 7.9mm, circumference 9.4mm, diameter 3mm.

Larvae are dark black coloured actively moving and feeding on leaves.

3.3.3.h *Clania holmesi* (incertae sedis), Watt, 1898

(Plate 10, Figures. a-h)

Materials examined: 02, 11.9233° N 75.3126° E, Usha A U, Hostplant: *Casuarina equisetifolia*

Adult male: Medium-sized hairy moths, their whole body covered with long dark brown hairs, including legs, head abdomen and thorax. Wings are thickly covered with blackish-brown scales, antenna bipectinate and 20 segmented. Wing expanse 17-18 mm, forewing length 7.8 mm, forewing width 4.3 mm, forewing index 1.8 mm. legs are with long brown hair-like scale, epiphysis present on foreleg which measures 1.3 mm and tibial length is 1.6 mm, foreleg index 0.8 mm.

Wing venation: Twelve veins are present in the forewing; 10 veins are from dc. R3 and R4 stalked, widen at the tip and ends on the apex. Veins R5 and M1 originate from the anterodistal corner of dc and runs parallel to the apex. M2 and M3 are stalked and end on termen. CuA1 and CuA2 are parallel to the distal corner. Anal veins are

anastomosing, A1+2 reaching to posterior margin. Hindwings with eight veins, six veins from dc. Veins R1 and M1 are parallel, M2 and M3 stalked, CuA1 and CuA2 are also parallel to the distal corner. Anal veins are free.

Genitalia male: Elongated structure, measures 1.5 mm length, valvae short and symmetrical, 0.35 mm long, presence of sharp spine on the apex and valvae not protrude beyond the tegumen. Tegumen slightly wide and presence of two flap-like structures at the apex. Vinculum Y shaped and narrowing distally, saccus narrow and blunt at the apex. Phallus long and tubular, length 1 mm, anterior tip of the aedeagus is triangular in shape.

Pupal exuvia (male): Dark brown colour, 9-10 mm length.

Larva: Body blackish, head capsule reddish brown with black patches, hairs are present on epicranium and frons region.

Three species descriptions are available for the spirally arranged type of larval bags, the species are *Clania holmesi* Watt, 1898, *Mahasena taprobana* Hampson 1910 and *Mahasena poliotricha*. Only larval cases have been described for *Clania holmesi* by Watt in 1898 and it is unclear whether it may be identical to *M. taprobana*. The spiral-shaped bags are unique for this species. Detailed descriptions of adults are not available for this species till now, so a change in both genus and species is possible in this insect, which need further evaluation. The current study retained the name of the species as *Clania holmesi* incertae sedis, the primarily described name of this species.

Subfamily: Metisinae Sauter & Hättenschwiler, 1999

3.3.3.i. *Metisa canifrons* Hampson, 1910

(Plate 11, Figures. a-h)

Materials examined: 01, 9.8584° N 76.9528° E, Usha A U, Hostplant: *Phyllanthus emblica*

Male moths are medium-sized blackish insects, wings are covered with blackish-brown hair-like scales and scales are evenly distributed on both wings. Wingspan 21-23 mm, length of body 9-10 mm, forewing length 9.5 mm, forewing width 7 mm, forewing index 1.3 mm and the veins are darker. The dorsal side of the body with brown

hairs and the ventral side of the head, thorax and abdomen is covered with white hairs. Head to thorax length 3.3 mm, abdomen long, 3.4 mm in length.

Antenna bipectinate and 20 segments, ciliated on both sides of each segment, antenna length 2.6 mm. Eyes are large. Legs are dark brown coloured, covered with a mixture of white and brown hairs and a long epiphysis is present on the foreleg.

Wing venation: Forewing with 12 veins, 10 veins from dc. Vein Sc and R1 are adjacent, Sc from the base ends in the middle of costal margin. R1 originates from the middle of the anterior part of dc and ends on the $\frac{3}{4}$ length of the apex of costa. Vein R3 and R4 stalked from the middle and widen to the apex. R5 originates from the stalked vein of R3, R4 from the anterior apex of dc. 6th vein present, M2 and M3 are stalked from the posterior apex of dc. CuA1 and CuA2 are almost parallel to the distal end. Anal veins are anastomosing, A1+2.

Hindwings with 8 veins, 7 veins from dc. The median stem of the dc divides to form an accessory cell. Sc is short from dc to the costal margin. M1 is straight from the middle dc to the apex. Veins M2 and M3 run very adjacent and parallel. Anal veins are free.

Genitalia male highly sclerotized and oval-shaped structure, 0.7 mm in length. Valvae are symmetrical and long, length 0.423 mm. Strong spines and long hairs were present at the tip of each valva. Tegumen-wide and bilobed, hairs are present on the margins. Vinculum broad and oval-shaped, saccus wide and blunt apex. Phallus long and broad, slightly widen at the apex, length 0.57mm.

Pupal exuvia: Light brown colour in both sexes, male exuvia length 11 mm, female 13 mm.

Larvae: An adult larva is 9 mm in length, pale yellow body with a highly sclerotized head and weakly sclerotized prothorax, head capsule is pale yellow with black patches. Well-developed thoracic prolegs and very short abdominal prolegs. The last abdominal segments and anal prolegs are brownish.

Female: Adults showing sexual dimorphism, female adults are vermiform without any appendages.

3.3.3.j. *Metisa plana* Walker, 1883

(Plate 12, Figures. a-g)

Materials examined: 03, 11.2587° N 75.7803° E, 10.3120° N 76.1325° E, Usha A U,
Hostplant: nil

Adult male moths are medium-sized, pale brown colour insects. Wingspan 18- 20 mm. Wings are thinly covered with hair-like light brown scales and the underside of both wings are covered with light whitish hair. Forewing length 8 mm and width 5mm, FI 1.6 mm. Body length of a moth is 5-5.5 mm. The head, thorax and underside of the abdomen are covered with thick white hairs. Eyes are large. Antenna bipectinate, 20 segments. The forelegs are with elongated epiphysis along the length of tibia.

Wing venation: Forewing 12 veins are present; 10 veins are from dc. The vein Sc arises from the base and runs towards the middle of the costal margin of the forewing. R3 and R4 are stalked to the apex. M2 and M3 are stalked from the middle region of dc. CuA1 and CuA2 are long and parallel to the distal end. Anal veins A1+2.

Hindwing with 8 veins; 7 veins are from dc. Sc+R1 and Rs are stalked from dc. M2 and M3 originate closely from the posterior apex of dc. CuA1 and CuA2 are long, almost parallel to the distal end. Anal veins are free.

Genitalia: Small, sclerotized, length 0.94 mm. Valvae are short, symmetrical, straight and flap-like lobe, and have fine hairs at the tip, length of 0.46mm. Tegumen wide arch-shaped and slightly inclined in the middle or bilobed. Vinculum U-shaped and saccus is pointed at the tip. Phallus is long, wide and round shaped at the apex, length 0.69 mm.

Pupal exuvia: Light brownish, the female pupae are larger than male in length and width.

Larva: Young instar larvae are very active, hair capsule reddish brown without patches at early stages, dark brown colour patches developed on the head at the final instar stage and body yellowish brown.

Female: Adults showing sexual dimorphism, females are vermiform, without any appendages.

3.3.3.k. *Pteroma plagiophleps* Hampson, 1892

(Plate 13, Figures. a-g)

Materials examined: 03, 10.4575° N 76.1523° E, 10.4420° N 76.2183° E, 19/01/2018, Usha A U, Hostplant: *Phyllanthus emblica*, *Delonix regia*

Adult(male): Small moths, brownish-black wings, the body is sparsely covered with hairs. Wing expanse 12 -13 mm. Antenna short, bipectinate, 15 segmented. Forewing length 5.4mm, forewing width 2.8 mm, forewing index 1.9 mm. Abdomen is long, 2.5 mm in length. Wings are partially covered with brown scales; forewings are almost triangular and hind wings are nearly round. Adults showing sexual dimorphism.

Wing venation: Forewing with 10 veins present, 8 veins from dc. The dc divides as larger anterior and smaller posterior parts. Sc and R1 run adjacently towards costa. Veins 6 and 7 are absent, R3 and R4 originate from the same point from dc to apex, M2 and M3 stalked to termen, anal veins anastomosing, A2+3 arrangement. Hindwings with 7 veins, six veins from dc, rounded, cells are open, vein 6 absent, a bar between veins 7 and 8 (Hampson, 1892, Mathew, 1985). CuA1 and CuA2 are parallel to the distal end. Anal veins are free.

Genitalia short, 0.54 mm length. Valva short and has a wide apex with short bristles anteriorly, 0.2 in mm length. Phallus short, broad tubular, 0.4 mm long and slightly pointed anteriorly. Tegumen broad and wide, bilobed, slight cleft in the middle and with short spines. Vinculum V-shaped and saccus is pointed apically.

Pupal exuvia male: Light golden brown in colour, 5mm in length.

Adult female: Vermiform body, pale-yellow abdomen, without any appendages and body filled with eggs. Body length 6 mm. The head is partially sclerotized and other parts are not sclerotized, appendages are rudimentary or absent.

Larvae body whitish cream colour, both the ends of the body sclerotized and darker brown in colour. Highly sclerotized head, epicranium white with dark brown colour patches. Thoracic legs are well developed and the tip of the leg is yellowish.

Subfamily: Eumasiinae Arnscheid & Weidlich 2017

3.3.3.1 *Eumasia thomasii* Usha et al., 2022

(Plate 14, Figures. a-h) (Plate 15 Figures. a-e)

Materials examined: Holotype; Male 10.18211° N, 77.25923°, 11/07/2022, with larval case, leg. Usha A U. Paratypes: 2 females (both with larval case), same data as holotype, 10/07/2022, Usha A U.

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1829

Subfamily Eumasiinae Arnscheid & Weidlich, 2017

Genus *Eumasia* Chrétien, 1904

Eumasia Chrétien, 1904: 120. Type species: *Coleophora parietariella* (Heydenreich, 1851)

Eumasia thomasii

Etymology. The adult female in most bagworm species is characterized by rudimentary appendages, eyes and no wings. But in this species both male and female are winged, have well developed eyes, legs and antennae. Therefore, the male and female adult moths are almost twin like. The word Thomas means ‘twin’ in aramic. The institution “St. Thomas College” in which the major part of the research was carried out is named for St. Thomas. Hence the species name “thomasii” alludes to the similar appearance of males and females and is also a homage to the institution.

Adult male holotype: Wingspan 8–8.3 mm; length of the body of male moth 2.5–3 mm; forewing length 4.1 mm including fringes; width 1.1 mm; WI 3.7 mm.

Head: Vertex roughly covered with pale golden-brown hairs. Eyes large, interocular index, EI 1.2 mm. Antenna short, filiform, 1.7 mm long, and 25 segments. Segments are sparsely ciliated, especially ventrally, dorsally with a fan-shaped process of dark brown scales, angle about 35° (according to Hättenschwiler 1998, personal communication Sobczyk T.).

Thorax: Densely covered with long brown scales. Forewings thickly covered with broad, mostly 5–6 pointed scales (classes 5–6 following Sauter 1956). Ground colour of the upper side of the forewing is greyish white marked with blackish-brown spots. Anterior margin without clear dark spots. An indistinct oblique band of dark scales from one-fourth of the anterior margin to half of the posterior margin. Another band from half anterior margin to half posterior margin. A third band is slightly distal to it.

The most conspicuous is a broad band of dark scales at three-quarters wing length. Distal to this, isolated dark scales towards the apex and outer margin. Fringes whitish, narrow, unicoloured and usually 3-pointed distally. Hindwing ground colour sliver white without any spots and markings, covered with white greyish-coloured scales. Scales narrower as fore wing, more rounded distally, few indentations. Outer margin with long whitish fringes.

Wing venation: Forewing narrow and lanceolate, costa straight and termen tapering at the apex. The discoidal cell is half the length of the forewing. Median stem of dc complete, but faded from middle to apex dc. Dc is bordered externally with transverse veins (not open, as in most *Eumasia* species). Forewing with nine veins, seven veins from the dc. Sc straight and ended up in the middle length of costa. R1 from dc is parallel to the vein Sc but originates a different length from the base. R2+3 and R4+5 run parallelly and end up on the costal margin at different lengths. M1 and R4+5 originate apically from dc reaching to apex. Veins R4+5 and M1 are not stalked at base but originate from the same point on the apex of dc. Veins M2+3, CuA1 and CuA2 are short and parallel to each other.

Hindwing are narrow and small, costa straight and vein Sc+R1 run adjacent to costa. Vein Rs and M1 are stalked and terminating to apex and termen respectively. M1 and M2+M3 run parallelly to termen. CuA1 and CuA2 are stalked and short. Anal veins are very short and almost invisible on the wings.

Forelegs ventrally with long hairbrush along with the length of tibia, hind legs are very long, 4.5 mm in length, covered with long whitish hairs on tibia and shorter hairlike scales on tarsal segments.

Abdomen: Abdomen long and thickly covered with blackish-brown scales.

Genitalia 0.86 mm long. Tegumen arched anteriorly and concave. Valva elongate and symmetrical, presence of hairs anteriorly. Vinculum V-shaped and saccus is very long and pointed at apex. Saccus two-thirds the length of the genitalia Phallus very long and straight tube-like structure, with a pointed tip, length 0.52 mm.

Adult female paratype. ♀ Winged; Body 3.5–4.2 mm long, stout and larger than males; wingspan 8–8.8 mm including fringes, Sizes of the wings of female and male are same, forewing length including fringes 4.1 mm, width 1.1 mm, forewing index 3.7

mm. Vertex is covered with thick pale golden coloured hairlike scales, antennae filiform, 23–25 segments, length 1.6 mm, completely covered with broad scales arranged in rings, slightly projecting distally, without cilia. Thorax is pale brown and sparsely covered with scales. Abdomen long, stout, pale-yellow, 3 mm long. White greyish scales on the abdominal segments and golden coloured hair tuft on the last abdominal segment. Forewing is thickly covered with light brown and blackish scales; blackish scales are arranged as spots on the forewings. Hindwings are without markings and patterns, densely covered with white greyish scales, outer margins of both wings are with long fringes.

Pupal exuvia. Pupal exuvia of both sexes light brown coloured. Length of a male pupal exuvia 2.6 mm, width 0.8 mm, in females 3.6 mm and width 1.0 mm.

3.3.3.m *Eumasia venefica* Usha et al., 2023

(Plate 16, Figures. a-g)

Materials examined: Holotype. ♂, Kerala, Nariyampara, Kattappana, Idukki, 9.7424° N, 77.0939° E, 28/10/2022, with larval case, leg. Usha A U.

Paratypes: one female (with larval case), same data as holotype, 19/10/2022, leg. Usha A U.

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1829

Subfamily Eumasiinae Arnscheid & Weidlich, 2017

Genus *Eumasia* Chrétien, 1904

Eumasia Chrétien, 1904: 120. Type species: *Coleophora parietariella* (Heydenreich, 1851)

Eumasia venefica

Type material. Holotype. ♂, INDIA, Kerala, Nariyampara, Kattappana, Idukki, 9.7424° N, 77.0939° E, 28/10/2022, with larval case, leg. Usha A U.

Paratypes: one female (with larval case), same data as holotype, 19/10/2022, 3 larval cases without pupal exuviae, leg. Usha A U.

Etymology: Larval bags have a ‘witches’ hat’ appearance, a disc-like anterior and a tubular posterior part. So, the word ‘*veneficus*’ means wizard. *Eumasia* is a female term

and the feminine gender of *veneficus* is '*venefica*', therefore the species name is '*venefica*'.

Description. Holotype ♂, Wingspan 8-8.2 mm, body length 3-3.2 mm, forewing length 3.8 mm including fringes, forewing width 1.1 mm, WI 3.4 mm, hindwing length 3.3 mm.

Head: Vertex densely covered with pale golden coloured hairs; the frons has a bilobed tuft of golden hairs. Eyes are large, EI 0.76 mm. Antenna thread-like, short cilia on segments, 26 segmented, 1.6 mm long.

Thorax: Covered densely with light brownish scales. Forewings are covered with pale brown and blackish scales. The scales are broad and have 5 pointed apices. Ground colour of the forewing is pale brown and the blackish scales in the forewing form patches and are randomly distributed on the wing surface. Hindwings are whitish without any spots and patterns and covered with pale golden scales. Wings are lanceolate, apex pointed, outer margin with long brownish fringe hairs. Legs are covered with long pale brownish hairs; the tarsal segments of the legs have darker scales or hairs. Hind legs are relatively very long.

Venation: Nine veins in the forewing, seven veins from the dc forewing. Veins M1 and R4+R5 are shortly stalked, a median stem divided dc two halves. Veins M2+3, CuA1 and CuA2 are short and parallel to each other. Hindwings are narrow and pointed, have seven veins and vein Sc+R1 runs parallel to the costal margin. Vein Rs and M1 are stalked. M1 and M2+M3 run as a separate vein to termen. CuA1 and CuA2 are shortly stalked. Anal veins are very short.

Abdomen: Densely covered with scales, the anterior portion of the abdomen is covered with pale brownish scales and the last abdominal segments and the tip of the abdomen are covered with blackish-brown scales.

Genitalia: Elongated, 1 mm in length. Tegumen arched apically. Valva is short and symmetrical, vinculum is very long. Saccus long and pointed at the apex. Phallus tubular, with a pointed tip, length 0.8 mm.

Paratype ♀: Winged, wingspan 9-9.3 mm, body length 4.2 mm, forewing length 4.5 mm excluding fringes, forewing width 1.3 mm, forewing index 3.4 mm, eyes are large,

ocular index 0.93 mm. Antenna thread-like with short cilia on segments. The head and area surrounding the eyes are densely covered with long golden hairs. Abdomen is long and stout, pale yellowish thinly covered with scales. Wings are lanceolate and narrow with long fringes. Forewings are densely covered with pale golden-brown scales. Dark brown scales are present and form patches and spots on the forewings. Four dark patches which are vertically arranged on each forewing are seen. When wings were folded close to the body, the spots on both wings came together to form a median band just below the anterior end. Hind wings are fully covered with pale whitish shiny scales without any markings. The wing venation is the same as in males. Legs are elongated and covered with long shiny white scales. The last abdominal segment has a long hair tuft surrounding the genitalia and a long ovipositor extended outside the last abdominal segment.

Larva: Larva is pale yellowish head is dark brown, highly sclerotized without any patches. A mature larva is 4 mm in length.

Subfamily Typhoniinae Lederer, 1852

3.3.3.n *Struthisca* cf *farinosa*. Mevrick, 1919

(Plate 18, Figures. a-g)

Materials examined: 02, Lat/Long: 9.9894° N 76.5790° E, 10.9142° N 76.2118° E, Usha A U, Hostplant: Nil

Adult male: Both sexes are fully winged, moths are small with wingspan 11-12 mm. The wings are densely covered with golden brown scales, hindwings are triangular with short fringes in the apex, forewing length 4.5 mm, WI mm. Antenna pectinate with short segments, 28-30 segments. Inter ocular index mm.

Adult female: The morphological characteristics are similar to the males, but the size of the abdomen is larger than males. Wingspan 13-14 mm, body length 5-6 mm, forewing length 6.8mm, forewing index 2.8mm. The last abdomen segment is covered with a light golden colour hair tuft.

Wing venation: Forewing with 11 veins present, 9 veins are from dc. Veins Sc and R1 combined, accessory cell absent. The veins R2, R3, R4 and R5 are free and almost parallel. Veins R5 and M1 arise from the dc adjacent to the apex. Veins M2, M3, CuA1

and CuA2 are short and parallel. Anal veins 1 and 2 are arising from the base separately and combined to form a single vein to termen. Hindwings with 5 veins from dc, no veins are stalked.

Genitalia male: Very small and 2 mm long. Tegumen arch-shaped, valva elongate and symmetrical, spines are present at the apex and long hairs are present on the outer margins of the valva. Vinculum Y-shaped, saccus is short, tube-like with a blunt end. Phallus is long, thorn shaped with a sharply pointed apex and wide base.

Pupal exuvia: Light brown, the length of a male pupal exuvia is 6 mm and the female pupal exuvia is 7-8 mm.

3.3.3.o. *Degiella* sp. nov., Sobczyk, 2009

(Plate 17, Figures. a-h)

Materials examined: 02, 10.9142° N 76.2118° E, 9.9894° N 76.5790° E, Usha A U,
Hostplant: Nil

Adult female: Medium-sized moths, wingspan 22-25 mm. Forewing length 11- 12 mm, WI 2.8 mm. Wings are long, oval and densely covered with golden brown scales on both the wings, presence of black scales on the forewing. Length of the body 8-9 mm, body is sparsely covered with hairs or scales. Antenna filiform, 38 segmented. Eyes are prominent and large, OI is 0.8 mm. Abdomen is elongated, 6 mm long, shiny white hair tuft seen on the last abdominal segment; the ovipositor is long extended to the outside as a long tube from the abdomen.

Wing venation: Forewing with 10 veins present, 9 veins from dc. Veins Sc and R1 combined and ends on half of the length of costa. Veins R4 and R5 are stalked, arising from the apex of dc. Median stem divided into two branches in the middle and forms an accessory cell, the branches end on the centre of the apex of dc separately. Veins M2 and M3 stalked, CuA1 and CuA2 runs parallelly. Anal veins 1 and 2 originate from the base separately and combined to form a single branch to the tornus. Hind wings with 8 veins present, 6 veins from dc. A small accessory cell present on the anterior part of dc, Rs and M1 stalked from the accessory cell to the apex. Veins M2, M3, CuA1 and CuA2 are parallel. Three anal veins are present.

Genitalia female: Anal hair tuft shiny white. The ovipositor is long and protrudes outside the abdomen as an elongated tube.

Pupal exuvia: Light brown, length 10 mm.

Larva: A final instar larva is about 8-9 mm in length, with yellowish-white body, the head is highly sclerotized, head capsule with longitudinal black patches on white background. The Pro thorax is light brownish with the same patches as in the head.

No other species from genus *Degiella* has been reported from India, therefore it is assumed that it is a species new to science. Further studies are being carried out before publishing the finding.

Subfamily Taleporiinae Herrich-Schäffer, 1857

3.3.3.p *Capulopsyche keralensis*, Usha et al., 2023

(Plate 19, Figures. a-f) (Plate 20, Figures. a-f)

Materials examined: Holotype, ♂ India, Kerala, Idukki, Nariyampara, 9.7424° N, 77.0939° E, 28/11/2022, with larval case, leg. Usha A U

Paratypes: 2 ♀, (both with larval case) same data as holotype, 16/12/2021, Usha, A. U. 2♂ (both with larval case) same data as holotype, 30/11/2022, leg. Usha, A. U

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1834

Subfamily Taleporiinae Herrich-Schäffer, 1857

Tribus Taleporiini Herrich-Schäffer, 1857

***Capulopsyche* gen. nov.**

Type species. *Capulopsyche keralensis* sp. nov.

Diagnosis. Males with fully developed wings, females wingless, without ocelli. Within Taleporiini, the number of veins from the forewing dc varies by genus. Palaearctic and oriental Taleporiini genera with nine of these veins and five dc-veins in the hind wing are known only in *Capulopsyche* gen. nov. The other genera (*Bankesia* Tutt, 1899, *Kozhanchikovia* Saigusa, 1961 and *Altobankesia* Dierl, 1966) have six dc-veins in the hind wing. On the other hand, genera with five dc-veins in the hindwing are distinguished by fewer dc-veins in the forewing: *Sciopetris* Meyrick, 1891 with eight

and *Solemasia* Zagulajev, 1996 with seven veins. The three genera from Southern Africa, *Barbaroscardia* Walsingham, 1891, *Lythrophila* Meyrick 1918, and *Thranitica* Meyrick, 1908 have six dc-veins in the hind wing. While *Bankesia* and *Altobankesia* have an additional cell in the dc forewing, *Kozhantshikovia* and *Solemasia* Zagulajev, 1996 lack it. *Kozhanchikovia* has very narrow, Y-shaped scales and a long saccus, in *Pseudobankesia* Meier, 1963, *Taleporia* Hübner, [1825], *Bankesia* Tutt, 1899, and *Sciopetris* Meyrick, 1891 the scales are very wide and the saccus is shorter. The larval bags differ significantly from the other known Taleporiini larval bags. The bags are double-walled. The inner bag is tubular and its lumen is round. The outer bag is wide with a curved top. It is shorter than the inner bag. The larval bags are hung on threads for pupation.

Etymology: *Capulo* (Latin) coffee refers to the moth being recorded from coffee plantations and to the predominant colour of the moth and *psyche* (Latin) butterfly, psychid.

Description. Male. Head. Vertex and frons covered with semi-erect scales, and a tuft of hairs projecting dorsally in the frons area. Occiput with densely arranged slender scales with bidentate apices, and these scales are also present in the surrounding areas of eyes, Eyes small, ocelli absent. Labial palpi curved upwards, three-segmented. Antenna short, filiform segments ciliated on both sides and dorsally with small scales.

Thorax. Barely covered with scales on the dorsal side. The forewing and hindwings are thickly covered with scales, the outer margins of both pairs of wings have fringes, the forewing fringes are short and broad and the hindwing fringes are very slender and long. Forewings nearly oval-shaped, WI 2.6 mm. Nine veins from forewing dc, accessory cell absent. Hindwings are shorter than forewings, length of 2.9 mm including fringes, WI 2.92 mm. Five veins from hindwing dc and frenulum as a single bristle. Foreleg with a long hairbrush originating from the middle length of the tibia and extended along with the tarsal segments. Midleg with one pair, hindlegs with two pairs of tibial spurs. Spurs of each pair of clearly different lengths.

Abdomen. Densely covered with scales, length 1.5 mm.

Genitalia. Length 0.46 mm. Tegumen elongated, posterior margin arched, deeply notched in the middle, ending in two curved thorns. Valva broad, curved inward,

surmounting the posterior border of the tegument, rounded distally, with numerous setae. Sacculus attached basally, ending in a strong curved spine. vinculum short, V-shaped, saccus short and pointed. Phallus short, tube-like, length 0.23 mm.

Female. Wings reduced to tiny, structureless lobes, without scales. Antenna short, eyes present. Legs with reduced tarsal segments. Length 2.5–3 mm.

Capulopsyche keralensis sp. n.

Type material. Holotype, ♂ India, Kerala, Idukki, Nariyampara, 9.7424° N, 77.0939° E, 28.xi.2022, with larval bag, leg. Usha A U.

Paratypes: 2 ♀, (both with larval bag) same data as holotype, 16.xii.2021, leg. Usha A U; 2m# (both with larval bag) same data as holotype, 30.xi.2022, leg. Usha A U; additional 24 larval bags with pupal exuviae, same data as paratypes, leg. Usha A U; 4 larval bags with pupal exuviae, Nelliampathy, Palakkad, Kerala, 10.5013° N, 76.6768° E, 15.ii.2022, leg. Usha A U

Diagnosis. See the diagnosis for the genus.

Etymology. ‘*keralensis*’ is derived from the state of Kerala in India. The binomial meaning Coffee Psychid of Kerala.

Description. Male. Small-sized brownish black moth, wingspan 8–8.4 mm, body length 2.9 mm, forewing length 3.7 including fringes, width 1.4 mm.

Head. Vestiture yellowish brown, the base of the antennae is thickly covered with dark yellowish-brown scales with bidentate apices. Antennae have total length 1.7 mm, flagellomeres 24 segmented. EI 1.13 mm.

Thorax. Reddish brown, barely covered with scales on the dorsal side. Forewings covered with dark brown scales mixed with yellowish scales. Scales broad (class 5-6), rounded distally, with 5-8 tips. The darker scales are mainly in the area of the front and outer margin and are partly arranged in irregular transverse bands. Fringes dark, wide, multi-pointed Hindwings dark greyish brown, slightly lighter at the base. Width 1.4 mm, WI 2.6 mm. Wing venation as described for genus.

Abdomen: Small, covered with blackish scales, length 1.6 mm.

Leg: As described for genus

Genitalia: As described for the genus.

Female: Body pale yellowish, around the abdomen, loosely covered with very narrow, distally rounded brownish black scales. Eyes are very small, EI 2.3 mm. legs short, reduced. Femur and tibia present, tarsi reduced to 2-3 segments, with two distinct claws, pale yellowish brown. Antenna short, filiform, 0.5mm long, with 6-9 different segments and the two basal segments are wider than others. The distal end of the abdomen with long ovipositor, surrounded by an anal tuft made up of long golden-brown hairlike scales.

Larva: Body whitish cream colour, head highly sclerotized. First and second thoracic segment dark brown, strongly sclerotized dorsally, third thoracic segment more strongly sclerotized at the posterior margin. The abdominal segments were without sclerotised fields for the setae and the anal shield only slightly more sclerotized. Fully grown larva 4 mm in length.

Male and female pupal exuvia: Dark golden-brown colour, male exuvia 3- 3.5mm in length and 1 mm in width, female exuvia 3.8 - 4 mm in length and 1.5 mm in width. A single row of spines dorsally on abdominal segments IV-VIII. The spines are directed backwards. Each row with a comb-like appearance, with numerous tiny hair-like spines. They probably serve to fix the pupa, later to move the pupa towards the exit and to hold it in place when hatching. In female pupae, the spines are shorter and reduced.

There are many eggs wrapped with silken cases seen inside the female bags, and female adults lay eggs using their ovipositor inside the bag after mating. Each yellow-coloured egg is wrapped inside individual silken cocoons and they are clustered together to form a group egg mass inside the sheath of the bag.

3.3.4. COI Sequencing and Phylogeny analysis of species

Table 7: GenBank accession numbers and details of COI sequences of all species from the study area

Sl No	Sample number	GenBank Accession number	Name of the Species
1	PSU01	MN717271	<i>Eumeta crameri</i>
2	PSU02	-	Unidentified sp.2
3	PSU04	ON615605	<i>Acanthopsyche cana</i>
4	PSU05	-	Unidentified sp.4
5	PSU06	OM980679	<i>Eumeta variegata</i>
6	PSU07	MN717272	<i>Manatha albipes</i>
7	PSU08	-	<i>Clania holmesi</i> (incertae sedis)
8	PSU09	OK489809	<i>Pteroma plagiophleps</i>
9	PSU10	-	Unidentified sp.8
10	PSU11	-	Unidentified sp.1
11	PSU12	MN717271	<i>Eumeta crameri</i>
12	PSU13	OM185573	<i>Metisa plana</i>
13	PSU14	-	<i>Acanthopsyche</i> sp.
14	PSU15	-	<i>Degiella</i> sp.
15	PSU16	-	<i>Struthisca</i> cf <i>farinosa</i>
16	PSU17	ON584252	<i>Acanthopsyche alstoni</i>
17	PSU18	ON602039	<i>Metisa canifrons</i>
18	PSU19	ON602040	<i>Acanthoecia larminati</i>
19	PSU20	OP957497	<i>Capulopsyche keralensis</i> Nelliyampathy
20	PSU20R	OP960232	<i>Capulopsyche keralensis</i> Nariyampara
21	PSU21	OP302728	<i>Eumasia thomasii</i>
22	PSU22	OR044899	<i>Eumasia venefica</i>
23	PSU23	-	Unidentified sp.3
24	PSU24	-	Unidentified sp.7
25	PSU25	-	Unidentified sp.6
26	PSU26	-	Unidentified sp.5
27	PSU27	-	<i>Eumasia</i> sp.
28	PSU28	-	Unidentified sp.9

3.3.5. Phylogenetic tree analysis

Neighbour-Joining tree (Fig. 2) shows a hypothetical taxonomic unit representing a Psychidae ancestor splits into two branches, the first group represents the species belonging to subfamilies Oiketicinae and Metisinae with sixteen species. The second group had three clusters each having species of the remaining subfamilies; Typhoniinae, Taleporiinae and Eumasiinae. The first group again split into two major branches, the first one with twelve species of subfamily Oiketicinae and second branch with three species of Metisinae. While *Clania holmesi* has been placed in Oiketicinae, here it showed more affinity to Metisinae. An unidentified species was also placed similarly. Earlier Metisinae was not recognised as a separate subfamily and was placed under Oiketicinae. Even now the species under both subfamilies seem to share a closer relation. *Manatha albipes* seems to have broken off earliest as a separate branch followed by another single branch representing unidentified species (PSU23). This branch is connected to the cluster of genus *Eumeta*, which was closer to *Acanthoecia larminati*, and a group of two unidentified species (PSU11 and PSU25). Species from genus *Acanthopsyche* and some unidentified species made up the second cluster of Oiketicinae. In the second group which had species from Metisinae and unidentified species, a single branch of spiral bag building bagworm species was grouped with a branch of an unidentified species (PSU02) which is then connected to *Metisa canifrons* as a single branch and then grouped with a cluster having two species *Pteroma plagiophleps* and *Metisa plana*.

The second branch splits from the hypothetical ancestor and divided into two groups. The cluster with species in the subfamily Typhoniinae had an unidentified species (PSU10) which connected to a cluster of two species *Degiella sp.* and *Struthisca cf farinosa*. The other branch which arises along with Typhoniinae split into two subfamily clusters, Taleporiinae and Eumasiinae. Taleporiinae branched out first and has one species *Capulopsyche keralensis*. This branch connects with a single branch which represents an unknown subfamily and the *Eumasia* cluster (Fig.2).

While COI and phylogenetic analysis was useful in validating the findings using conventional taxonomic methods it cannot be considered as a final representation of the evolutionary relationships in Psychidae because of the following reasons.

1. All species or at least a majority of species belonging to Psychidae from all over the world have not yet been discovered.
2. COI sequences of all identified species have not been uploaded in databases like BOLD or GenBank.

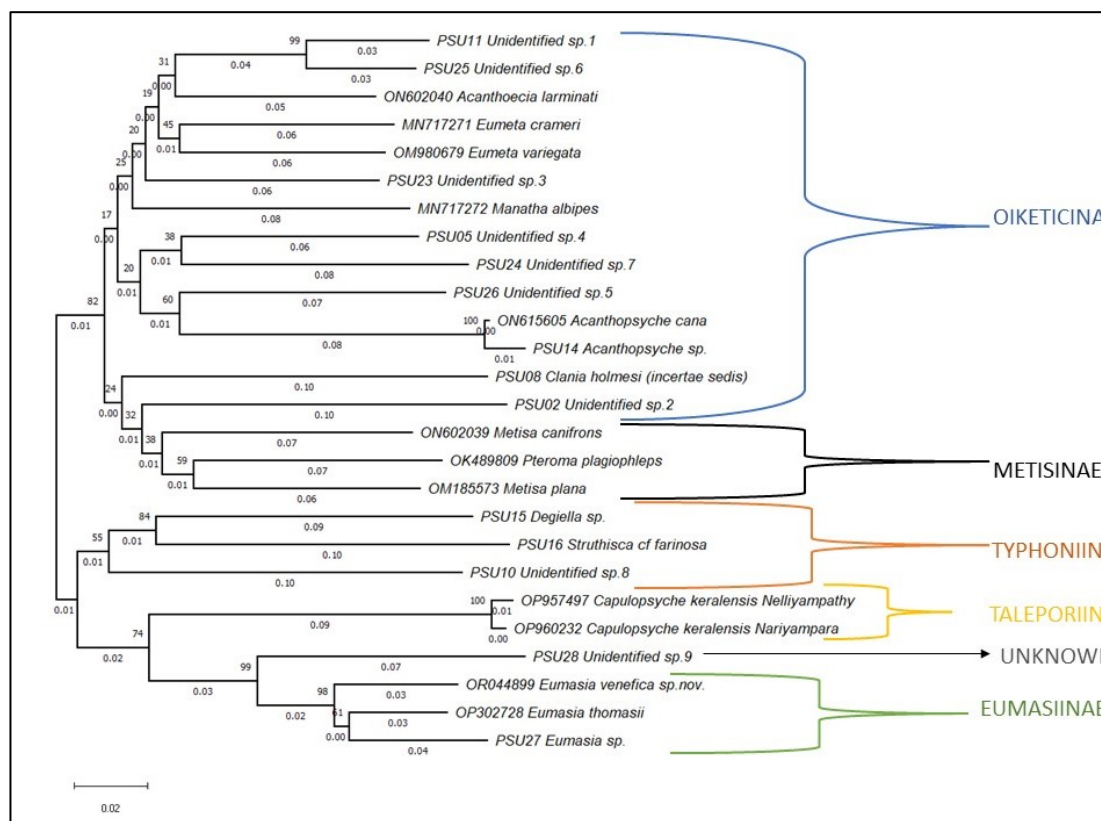


Figure 2: Neighbour joining tree of all bagworm species from the study area built using COI sequence

The nucleotide composition of the species, the average values and percentage of each nucleotide in the COI sequence of the species are given in the Table 8. The average value of thymine (T) is 37.69239877, adenine (A) 30.7601231, guanine (G) 14.2375089, and cytosine (C) 17.3099692. The average length of the COI sequence of the species is 625.6 bp. *Struthisca cf farinosa* and *Eumasia thomasii* has the lowest and highest value of thymine (T) respectively. *Eumasia venefica* and *Acanthopsyche sp.* has the lowest and highest value of cytosine (C) respectively. *Acanthopsyche sp.* and Unidentified sp. has the lowest and highest value of adenine (A) respectively. Unidentified sp (PSU24) and *Struthisca cf farinosa*. has the lowest and highest value of guanine (G) respectively. All the sequences almost followed Chargaff's rules.

Table 8: Nucleotide composition of COI sequences of bagworm species in the study area

Species	Nucleotide composition				
	T(U)	C	A	G	Total number of base pairs
MN717271 <i>Eumeta crameri</i>	37.8809 8694	17.271 4078	30.478 955	14.368 6502	689
PSU02 Unidentified sp.2	34.9112 426	20.414 2012	29.142 0118	15.532 5444	676
ON615605 <i>Acanthopsyche cana</i>	35.6164 3836	20.719 1781	29.623 2877	14.041 0959	584
PSU05 Unidentified sp.4	39.2803 5982	16.791 6042	30.584 7076	13.343 3283	667
OM980679 <i>Eumeta variegata</i>	40.2635 4319	14.934 1142	30.161 0542	14.641 2884	683
MN717272 <i>Manatha albipes</i>	38.1502 8902	16.473 9884	31.213 8728	14.161 8497	692
PSU08 <i>Clania holmesi</i> incertae sedis	34.0983 6066	19.836 0656	30.327 8689	15.737 7049	610
OK489809 <i>Pteroma plagiophleps</i>	34.7656 25	20.117 1875	30.859 375	14.257 8125	512
PSU10 Unidentified sp.8	35.5555 5556	17.142 8571	33.968 254	13.333 3333	630
PSU11 Unidentified sp.1	39.8518 5185	15.703 7037	29.037 037	15.407 4074	675
PSU12 <i>Eumeta crameri</i>	37.8861 7886	16.747 9675	31.544 7154	13.821 1382	615
PSU14 <i>Acanthopsyche sp.</i>	35.9477 1242	21.241 8301	28.758 1699	14.052 2876	612
PSU15 <i>Degiella sp.</i>	32.3624 5955	21.035 5987	32.200 6472	14.401 2945	618
ON602039 <i>Metisa canifrons</i>	38.7096 7742	16.422 2874	30.058 651	14.809 3842	682
ON602040 <i>Acanthoecia larminati</i>	37.4269 0058	16.959 0643	31.140 3509	14.473 6842	684

Species	Nucleotide composition				
	T(U)	C	A	G	Total number of base pairs
OP957497 <i>Capulopsyche keralensis</i> . Nelliyampathy	37.6146 789	15.596 3303	32.262 9969	14.525 9939	654
OP960232 <i>Capulopsyche keralensis</i> . Nariyampara	37.7535 1014	15.600 624	32.137 2855	14.508 5803	641
OP302728 <i>Eumasia thomasii</i>	41.3391 5575	14.410 4803	31.149 9272	13.100 4367	687
OR044899 <i>Eumasia venefica</i>	41.0687 0229	13.740 458	32.213 7405	12.977 0992	655
PSU23 Unidentified sp.3	38.3792 0489	17.889 9083	29.663 6086	14.067 2783	654
PSU24 Unidentified sp.7	37.6470 5882	18.823 5294	31.764 7059	11.764 7059	255
PSU25 Unidentified sp.6	40.2654 8673	15.191 7404	29.498 5251	15.044 2478	678
PSU26 Unidentified sp.5	39.4080 9969	16.199 3769	30.996 8847	13.395 6386	642
PSU27 <i>Eumasia</i> sp.	39.6666 6667	15.666 6667	31.5 6667	13.166 6667	600
PSU16 <i>Struthisca</i> cf <i>farinosa</i>	33.1738 437	20.893 1419	29.505 5821	16.427 4322	627
OM185573 <i>Metisa plana</i>	36.8421 0526	17.604 3557	31.578 9474	13.974 5917	551
PSU28 Unidentified sp.9	39.7415 1858	16.801 2924	30.048 4653	13.408 7237	619
Average value	37.6923 9877	17.309 9692	30.760 1231	14.237 5089	625.62963

3.4. Discussion

3.4.1. Taxonomy of Psychidae

This study documented twenty-six species from five subfamilies from the study area of which thirteen specimens are identified up to species level, three up to genus level and the remaining ten species were unidentified. The species were classified up to subfamily using the morphology of adult, larvae and bag and COI sequencing. Subfamily Oiketicinae had fifteen species including the unidentified species. The subfamily has five identified genera; *Acanthopsyche*, *Acanthoecia*, *Eumeta*, *Manatha* and one undetermined genus.

The study documented three different species of Genus *Acanthopsyche*. The species differ in size and morphology. *Acanthopsyche alstoni* is the smallest species in the Genus *Acanthopsyche*. The other species *Acanthopsyche cana* and *Acanthopsyche sp.* are medium-sized moths that differ in adult morphology and larval bag architecture. The COI sequence had variations as well. The head, thorax, and abdomen of *Acanthopsyche cana* are thickly covered with pale golden-brown hairs and the ventral side of the abdomen is thickly covered with dark golden-brown hairs and the wingspan 18 mm. The body of *Acanthopsyche sp.* is sparsely covered with brown colour hairs and wingspan 19 mm. The species confirmation of *Acanthopsyche sp.* is not possible at present due to the lack of enough adult specimens.

Genus *Acanthoecia* has only one species *Acanthoecia larminati*. Genus *Eumeta* has two species *Eumeta crameri* and *Eumeta variegata*, *E. variegata* is the largest species in the study and has a wingspan of 35-40 mm. Both species differ in wingspan, morphology, and larval bag architecture. Genus *Manatha* has only one species, *Manatha albipes*.

Subfamily Metisinae had three species from two genera *Metisa*, and *Pteroma*. In this subfamily, Genus *Metisa* has two species, *Metisa plana* and *Metisa canifrons*. Both species are considered pests of plants due to their poly phytophagous nature. *Metisa plana* is the smallest species in the genus. The wingspan differs significantly in both the species (18-20 mm in *M. plana* and 21-23 mm in *M. canifrons* respectively). The larval bag structure also differed in both species in size. But the basic structure, bag-building material, and ornamentations were similar in both species. Genus *Pteroma* has only one species *Pteroma plagiophleps*, which had a wingspan of 12 -13 mm.

Arnscheid & Weidlich defined the Eumasiinae subfamily in the Psychidae in 2017, based on the monotype genus *Eumasia* Chretien 1904. Fourteen species of *Eumasia* have been identified worldwide (Sobczyk 2011, 2015; Arnscheid and Weidlich, 2017) of which eight species are from the Palearctic and six species are from the Oriental region (Sobczyk 2011, 2015; Arnscheid & Weidlich 2017, Roh *et al.*, 2018). Nine species were reported from Asian countries, of which two were from India (Sobczyk 2011), namely- *Eumasia arenatella* (Walker, 1864): Sri Lanka, India, and *Eumasia exoria* Meyrick, 1919: India (Bengal, Pusa).

From the study area, subfamily Eumasiinae had three species, including two species new to science, *Eumasia thomasii* and *Eumasia venefica*, which adds the tally of described *Eumasia* from India to four when added with two species reported previously from India. A third *Eumasia* could be identified only till genus level. Species level identification is not possible at present due to the lack of adult male insects. Subfamily and genus confirmation was done by the COI sequencing and phylogeny analysis along with characteristics of larvae and female.

Subfamily Taleporiinae has one genus and species new to science, named *Capulopsyche keralensis*. The number of veins from the forewing dc varies by genus in this subfamily. The new genus *Capulopsyche* had nine dc veins in the forewing and five dc veins in the hind wing. The other genera (*Bankesia* Tutt, 1899; *Kozhantshikovia* Saigusa, 1961; *Altobankesia* Dierl, 1966) have six of these veins. While *Bankesia* and *Altobankesia* have an additional cell in the dc forewing, *Kozhantshikovia* and *Capulopsyche* have not.

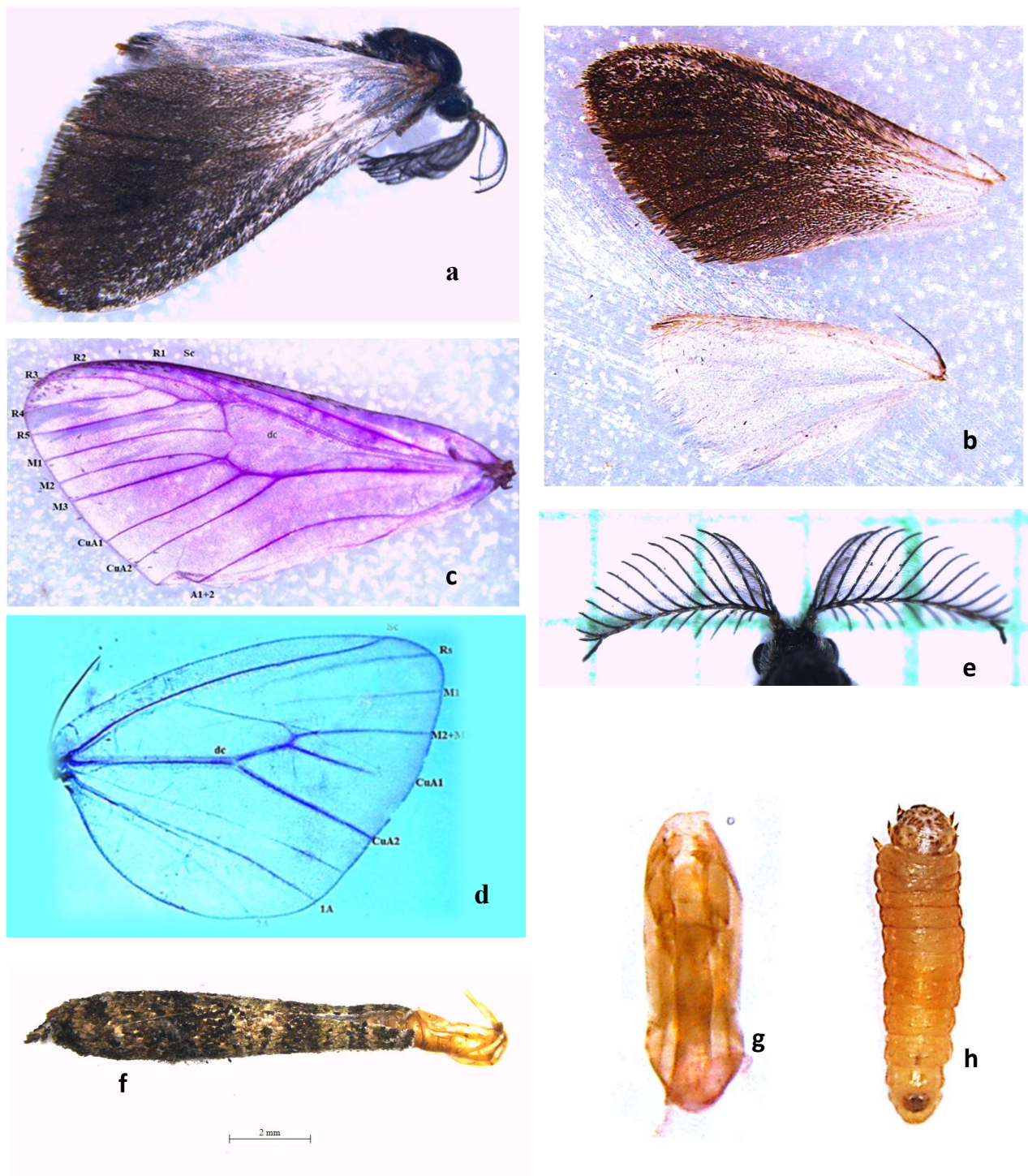
Subfamily Typhoniinae had two species identified with certainty up to genus level, *Degiella* sp. and *Struthisca* cf *farinosa*. Both species differ in wing venation and larval bag architecture. *Degiella* sp. has ten veins in the forewing, nine veins in the dc forewing, six veins from the dc hindwing and *Struthisca* cf *farinosa*. has eleven veins in the forewing, nine veins from the dc forewing and five veins from dc hind wing. COI sequencing has been done for all the identified and unidentified species. Subfamily-level classification was confirmed by the COI sequencing and phylogeny analysis.

3.5. Conclusion

The identification of species in Psychidae is only possible by the examination of adult male insects. Major taxonomic characteristics are present in the males whereas the characteristics of adult females and larval bags are useful for additional information or only for subfamily-level classification. More studies are needed to examine the taxonomic significance of other life stages of Psychids other than adult males. The present study faced many challenges to determine the species mainly because of the unavailability of males and the lack of previous studies. The bagworms without male adults could not be identified beyond subfamily level or genus level. In spite of these challenges, a detailed description of species which were identified at least up to the genera level was done. A taxonomic key was prepared for all identified genera. The study resulted in discoveries new to science which included one genus *Capulopsyche* gen. nov. in the subfamily Taleporiinae and the species *Capulopsyche keralensis* from coffee plantations in two districts of Kerala. Subfamily Eumasiinae had two new species, *Eumasia thomasii* and *Eumasia venefica* both inhabiting rocky areas. A neotype designation was done for the species *Acanthopsyche alstoni* with its adult redescription from India after 119 years.

PLATE 3

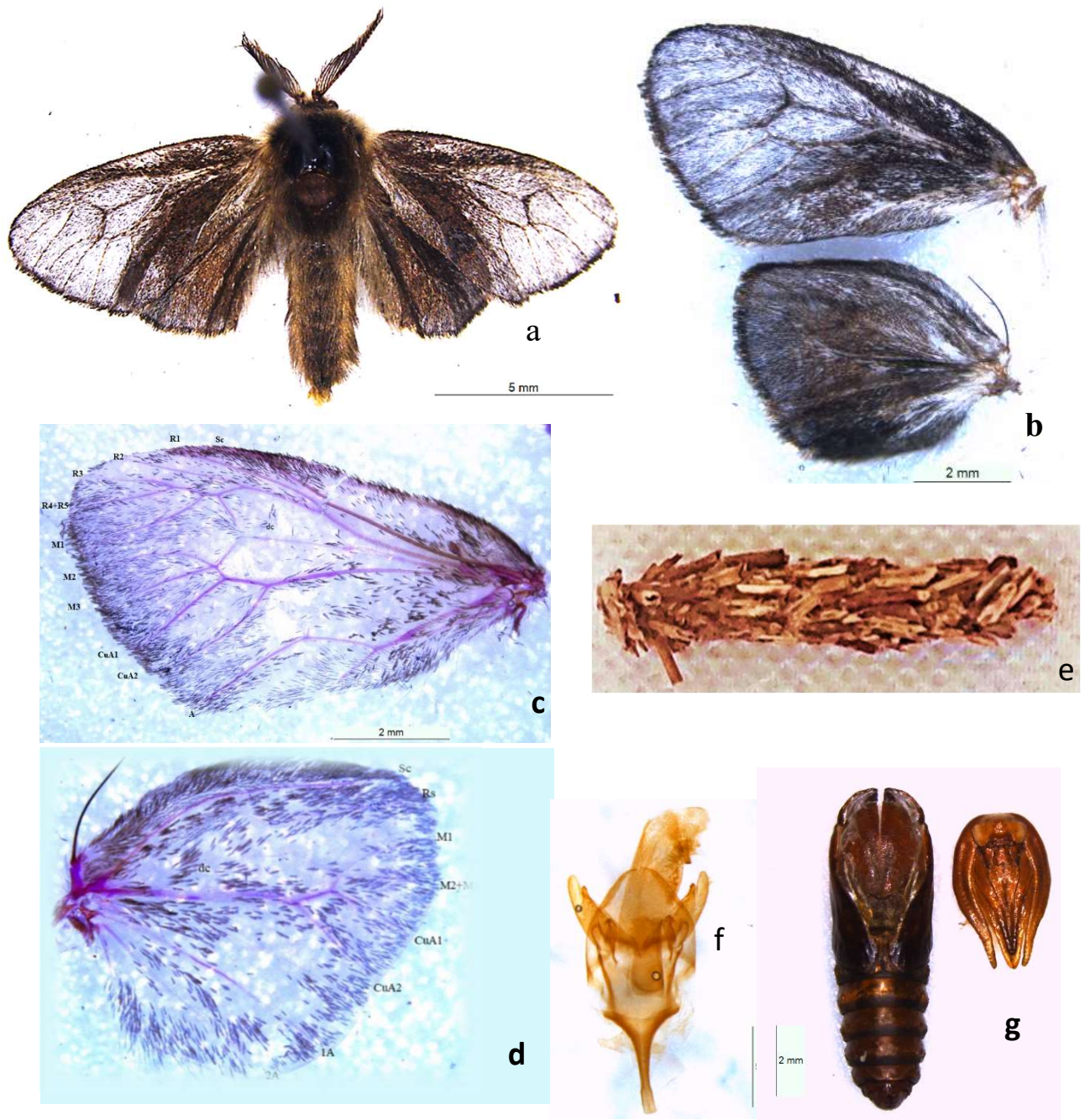
Acanthoecia larminati Heylaerts, 1904



Figures: a. Adult moth male, b. Forewing and hindwing male, c. Forewing venation, d. Hindwing venation, e. Antenna male, f. Male pupal bag with pupal exuvia, g. Genitalia male, h. Larva

PLATE 4

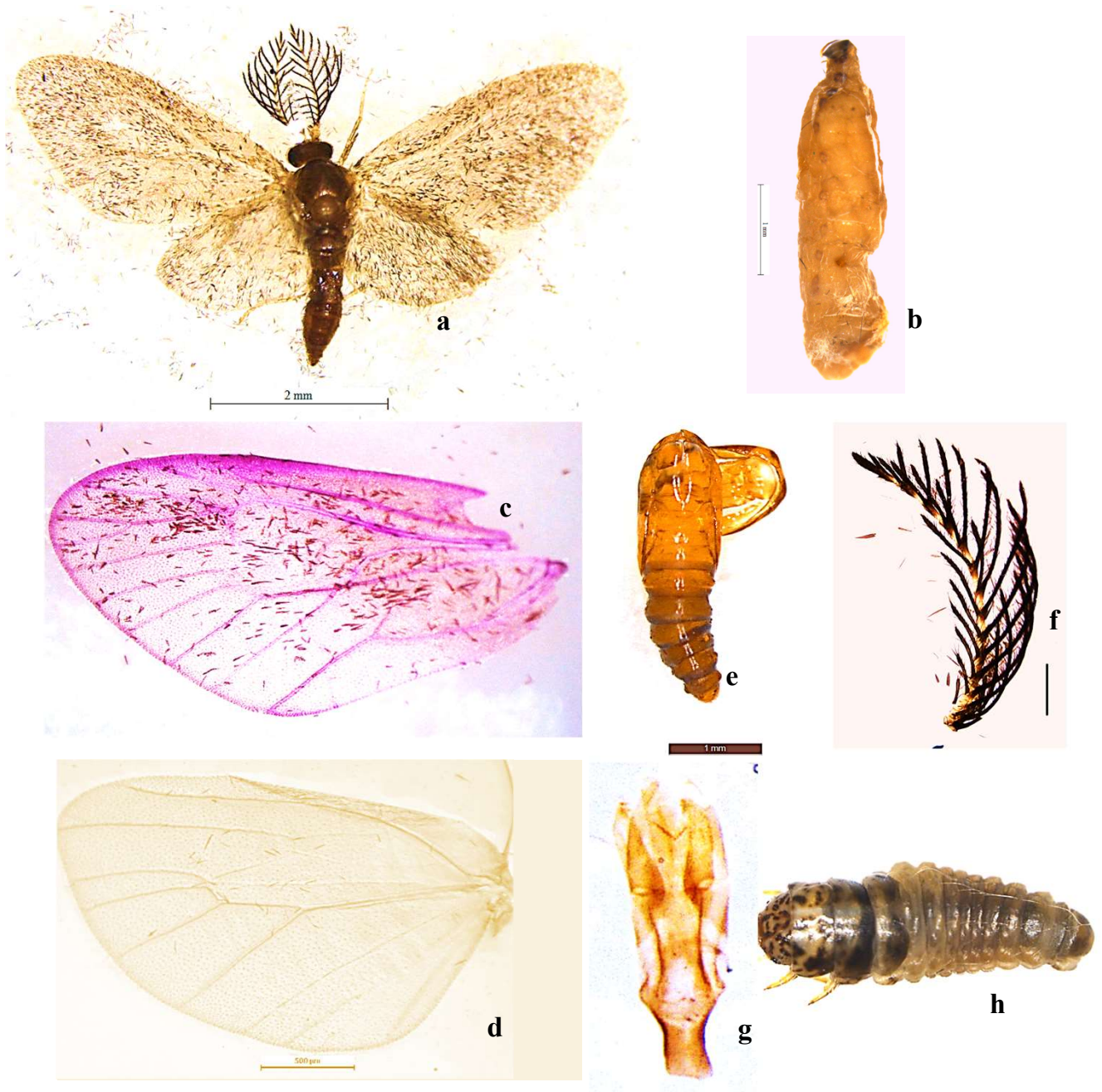
Acanthopsyche cana Hampson, 1892



Figures: a. Adult moth male, b. Forewing and hindwing male, c. Forewing venation, d. Hindwing venation, e. Pupal bag male, f. Genitalia male, g. Pupal exuvia male.

PLATE 5

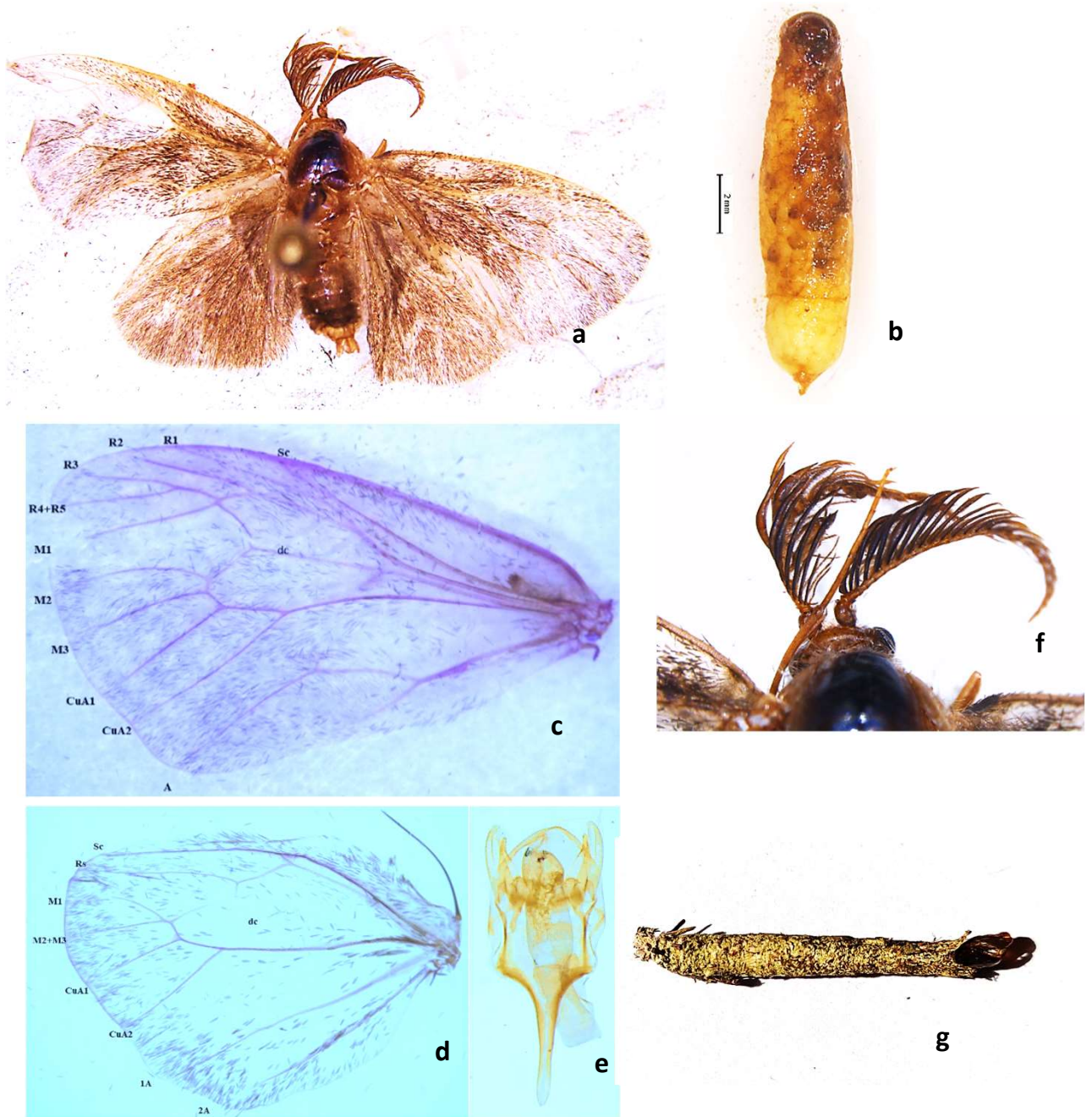
Acanthopsyche alstoni Watt & Mann, 1903



Figures: a. Adult moth male, b. Adult female, c. Forewing venation, d. Hindwing venation, e. Pupal exuvia male, f. Antenna male g. Genitalia male, h. Larva

PLATE 6

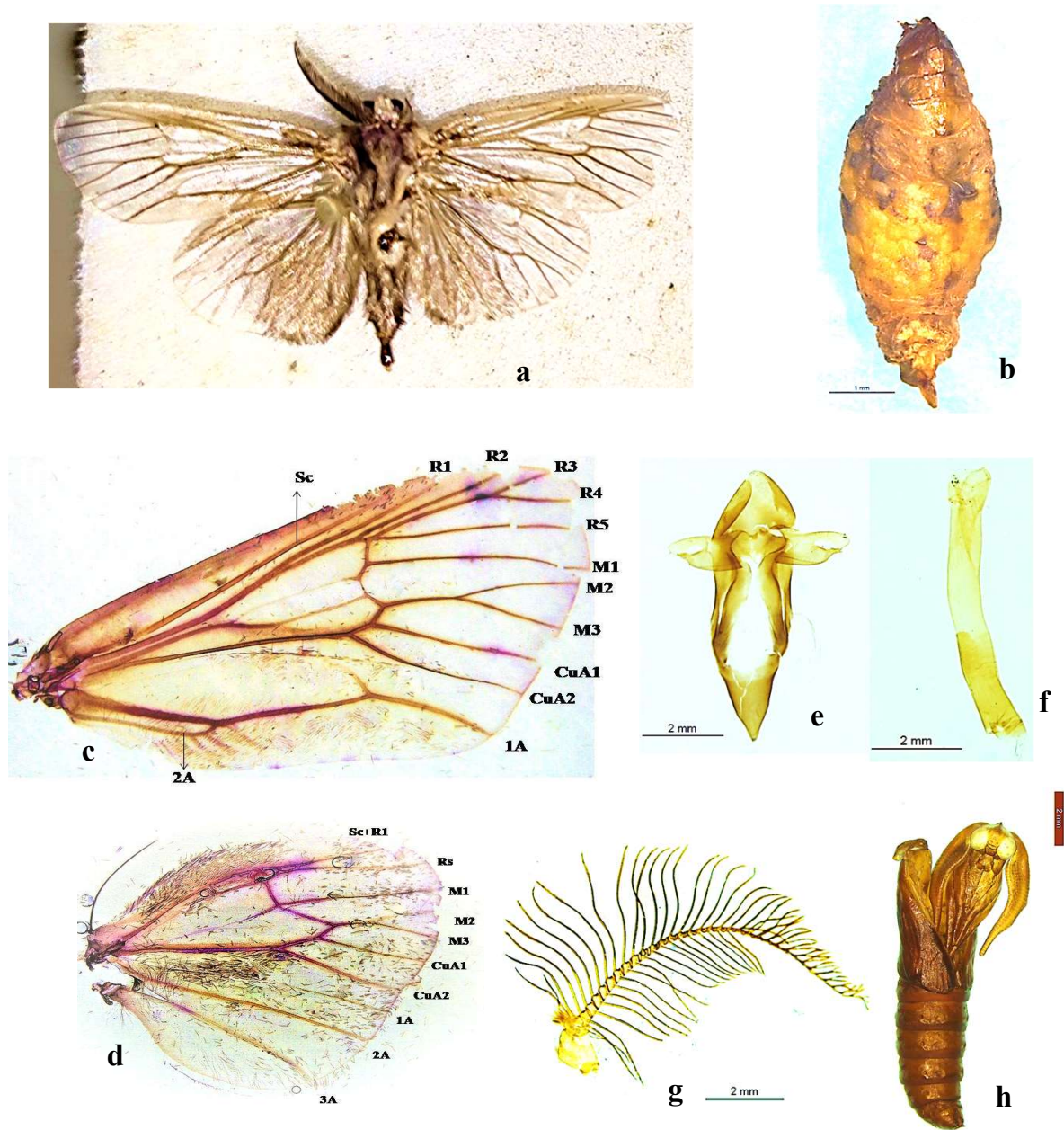
Acanthopsyche sp.



Figures: a. Adult moth male, b. Adult female, c. Forewing venation, d. Hindwing venation, e. Genitalia male, f. Antenna male, g. Pupal bag and pupal exuvia male.

PLATE 7

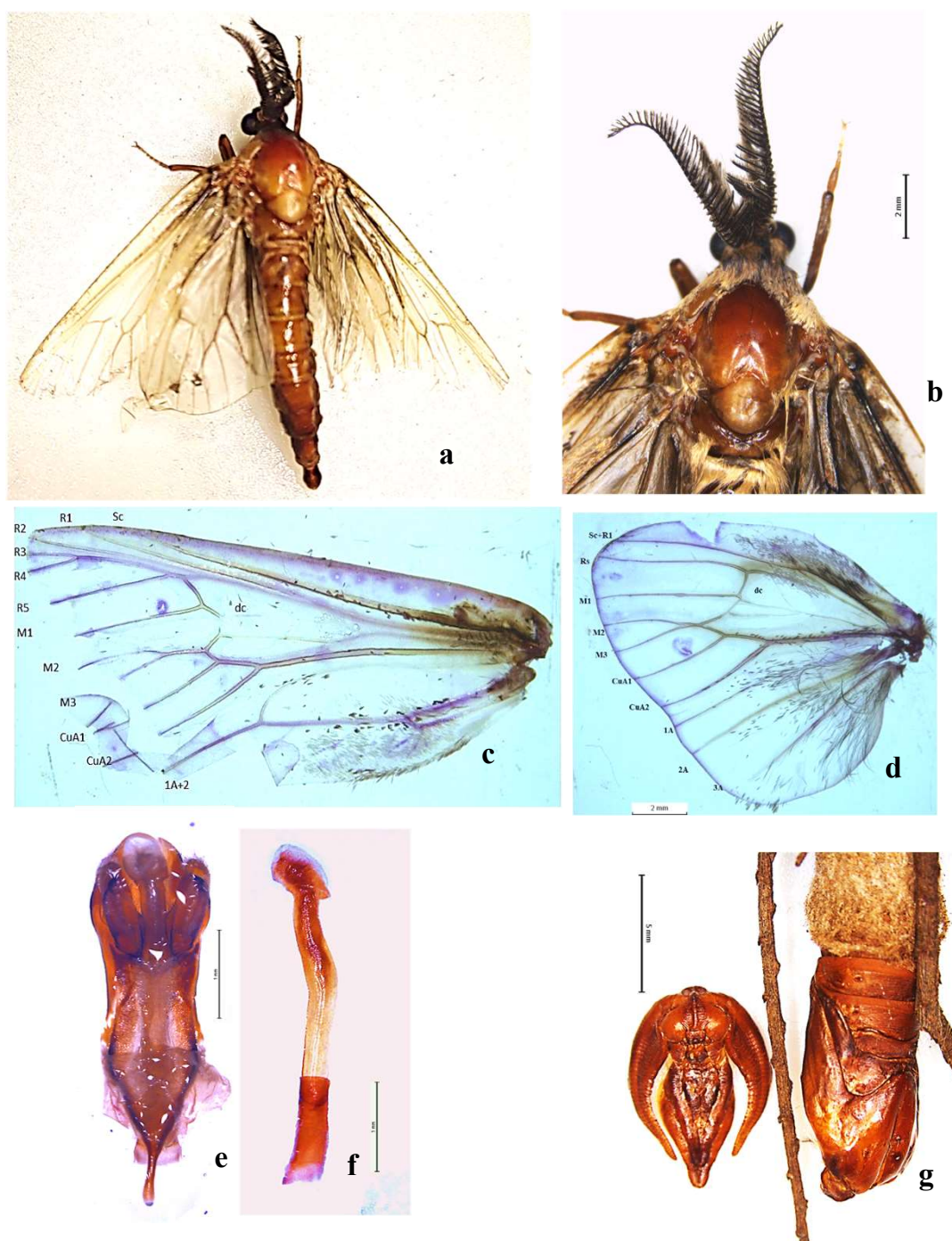
Eumeta crameri Westwood, 1854



Figures: **a.** Adult moth male, **b.** Adult female, **c.** Forewing venation, **d.** Hindwing venation, **e.** Genitalia male, **f.** Aedeagus male **g.** Antenna male **h.** Pupal exuvia male

PLATE 8

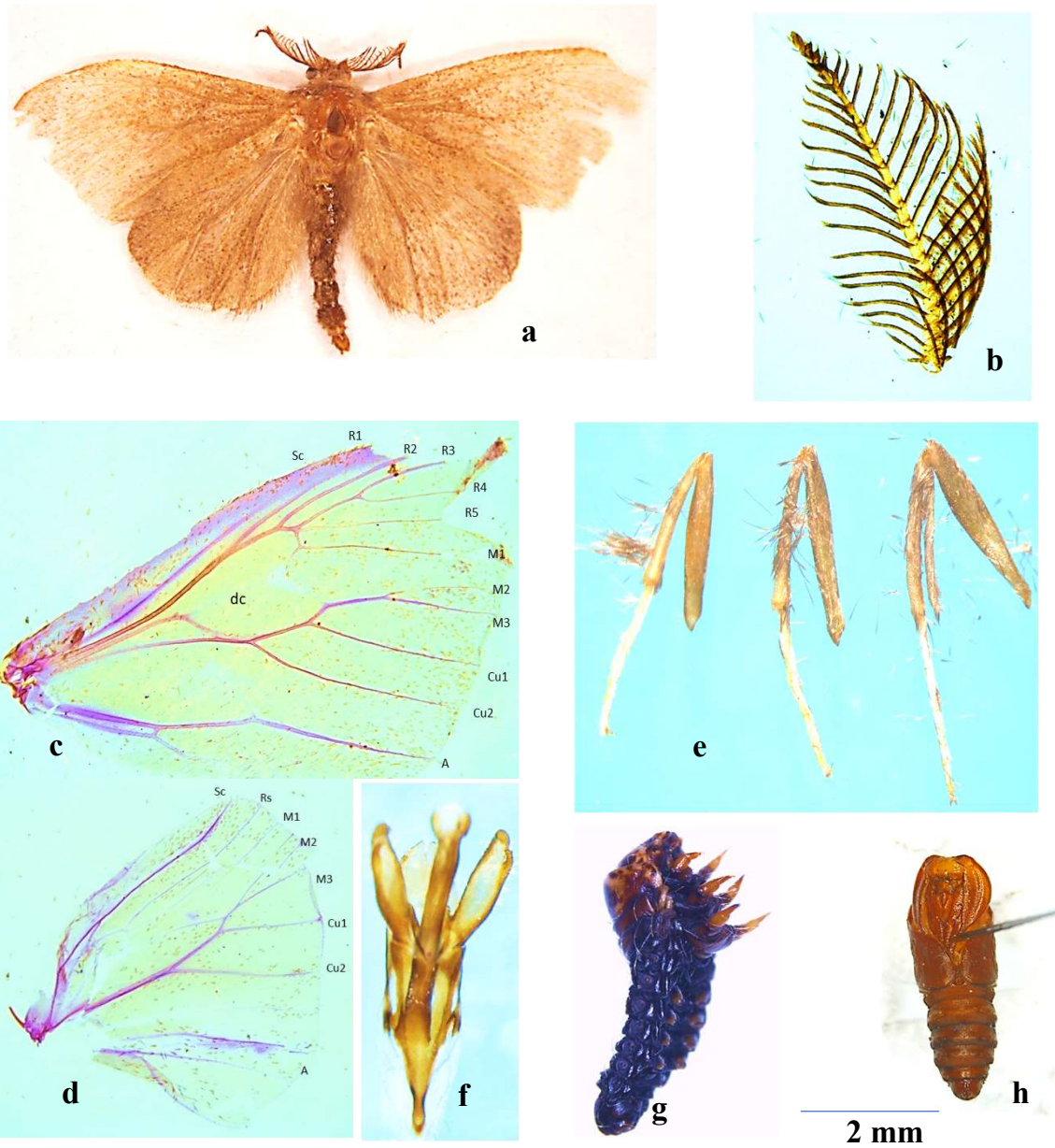
Eumeta variegata Snellen, 1879



Figures: **a.** Adult moth male, **b.** Antenna and thorax anterior view **c.** Forewing venation male, **d.** Hindwing venation male, **e.** Genitalia male, **f.** Aedeagus male **g.** Pupal exuvia male

PLATE 9

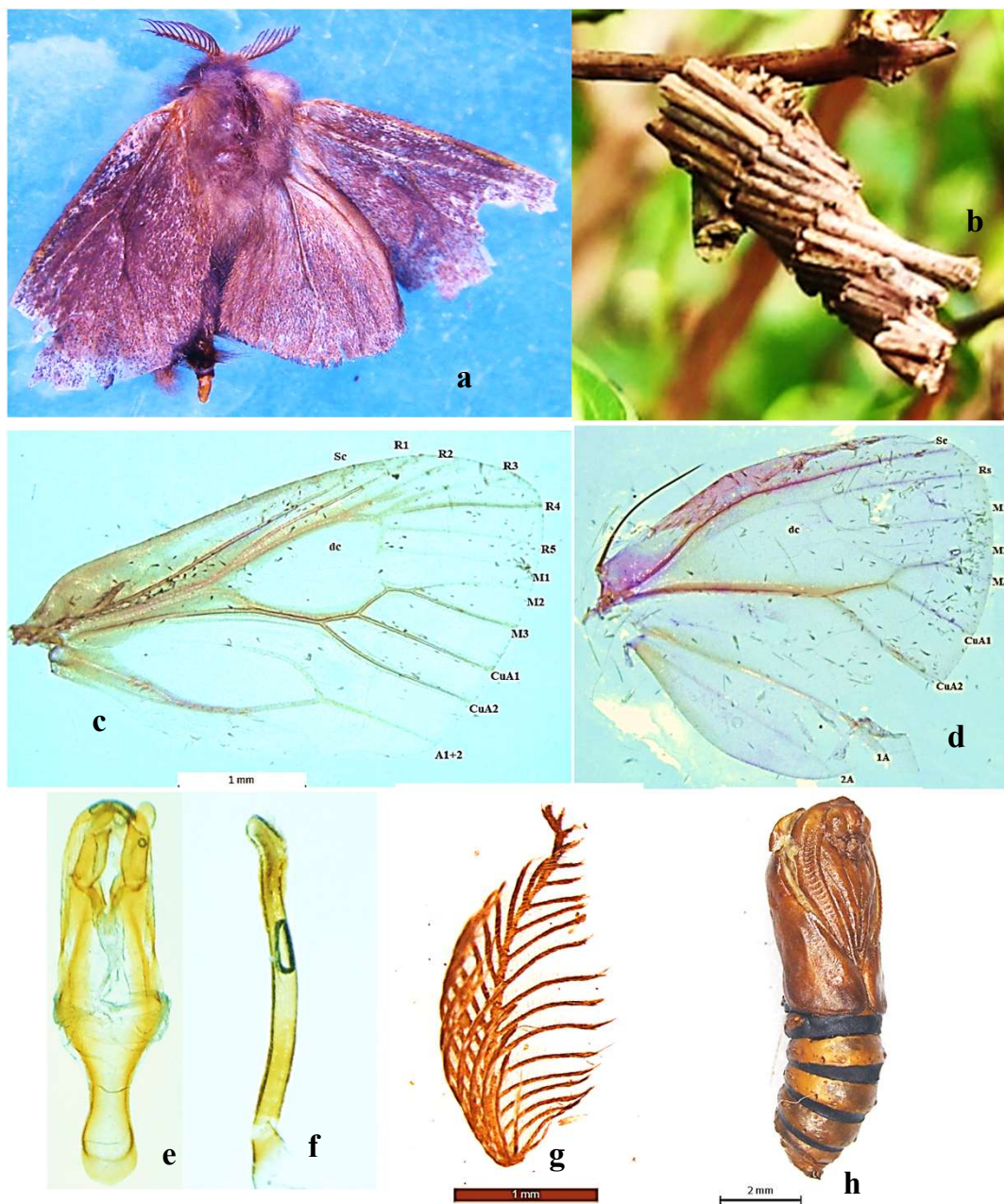
Manatha albipes Moore, 1877



Figures: **a.** Adult moth male, **b.** Antenna male **c.** Forewing venation male, **d.** Hindwing venation male, **e.** Thoracic legs male, **f.** Genitalia male **g.** Larva, **h.** Pupal exuvia male

PLATE 10

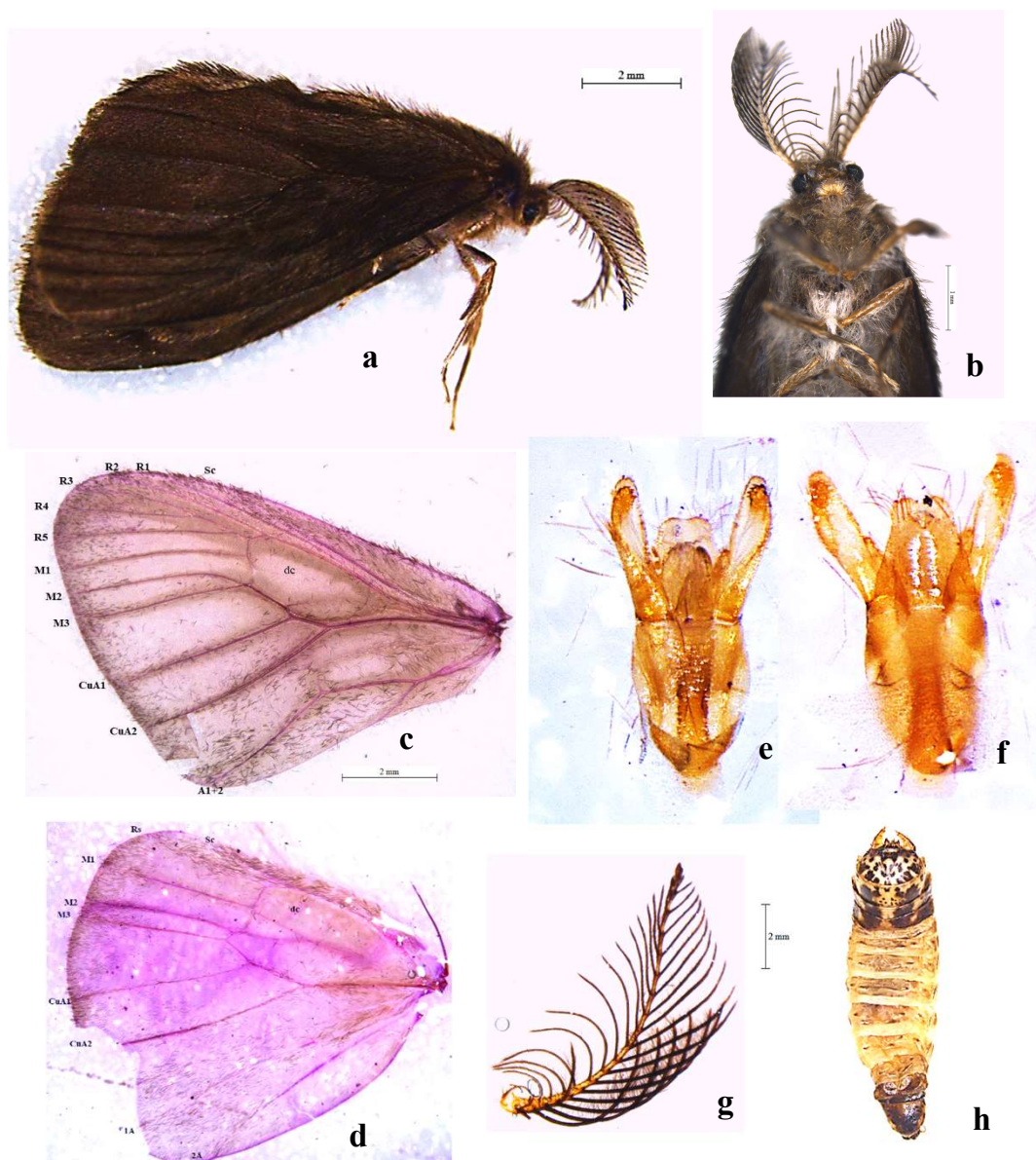
Clania holmesii incertae sedis Watt, 1898



Figures: a. Adult moth male, b. Pupal bag male, c. Forewing venation, d. Hindwing venation, e. Genitalia male, f. Aedeagus male g. Antenna, h. Pupal exuvia male

PLATE 11

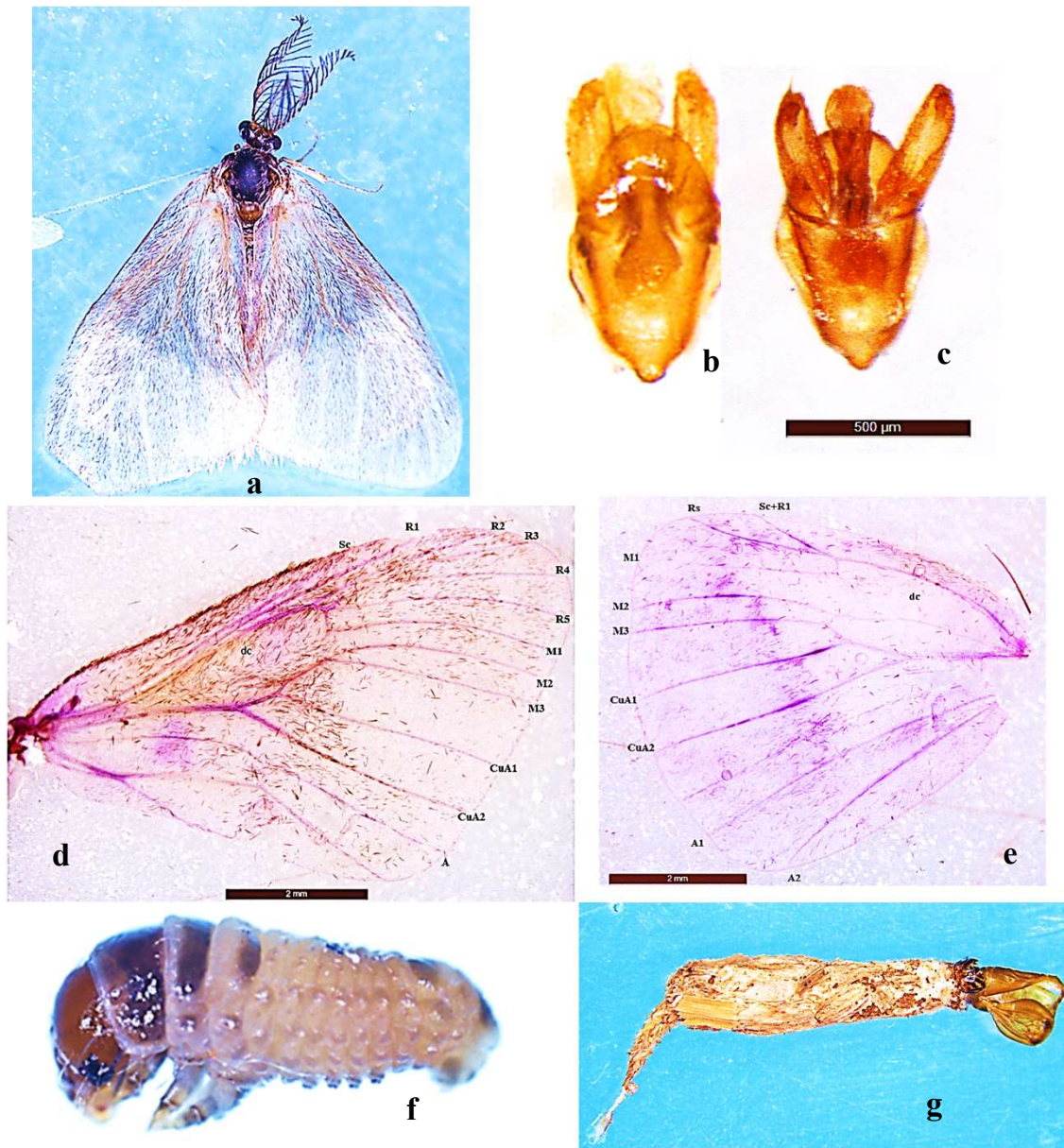
Metisa canifrons Hampson, 1910



Figures: **a.** Adult moth male, **b.** Moth head and thoracic legs, ventral view, **c.** Forewing venation, **d.** Hindwing venation, **e.** Genitalia male ventral view, **f.** Genitalia male dorsal view **g.** Antenna male, **h.** Larva

PLATE 12

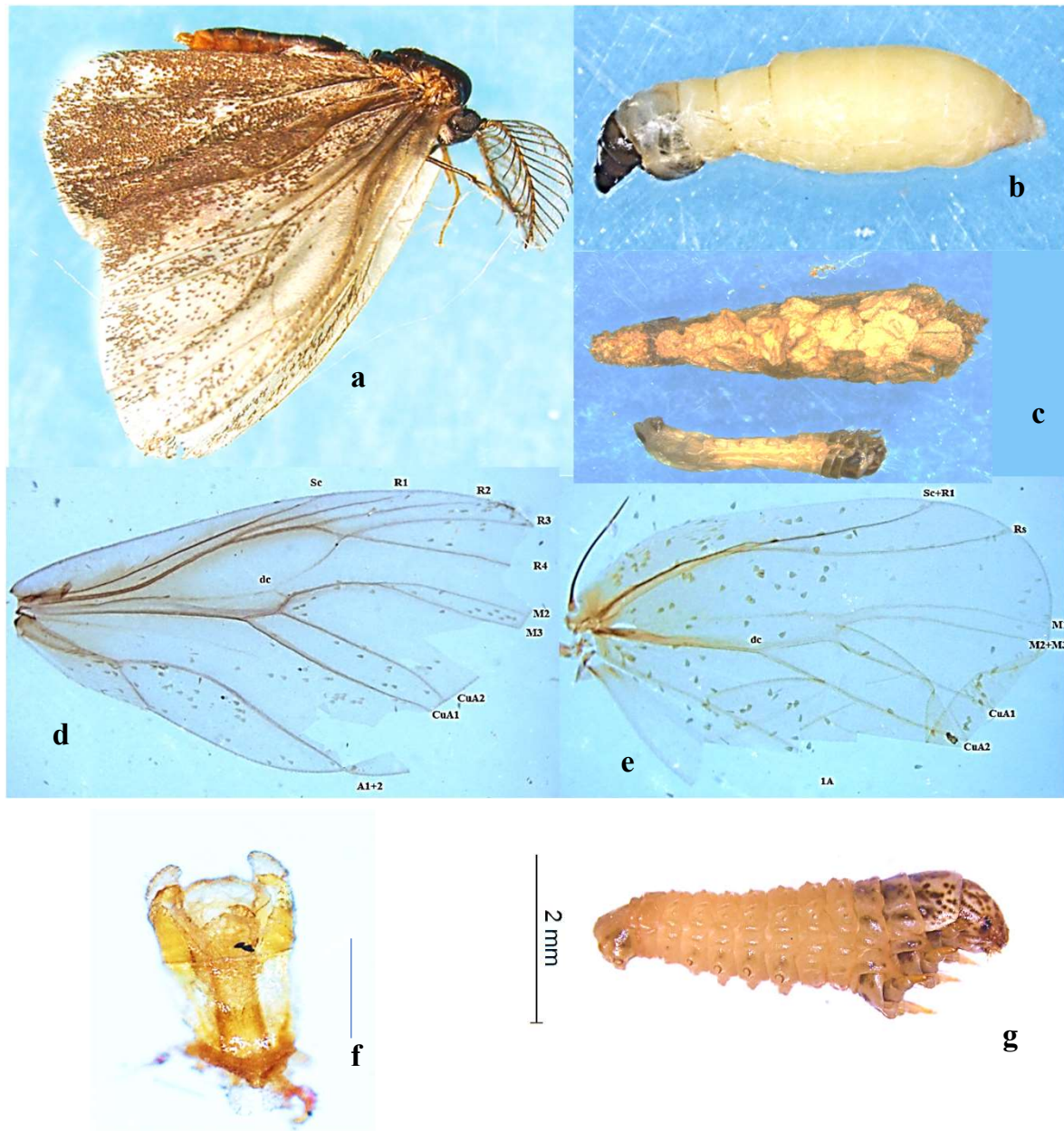
Metisa plana Walker, 1883



Figures: **a.** Adult moth male, **b.** . Genitalia male dorsal view **c.** Genitalia male ventral view, **d.** Forewing venation, **e.** Hindwing venation, **f.** Larva, **g.** Pupal bag with pupal exuvia male.

PLATE 13

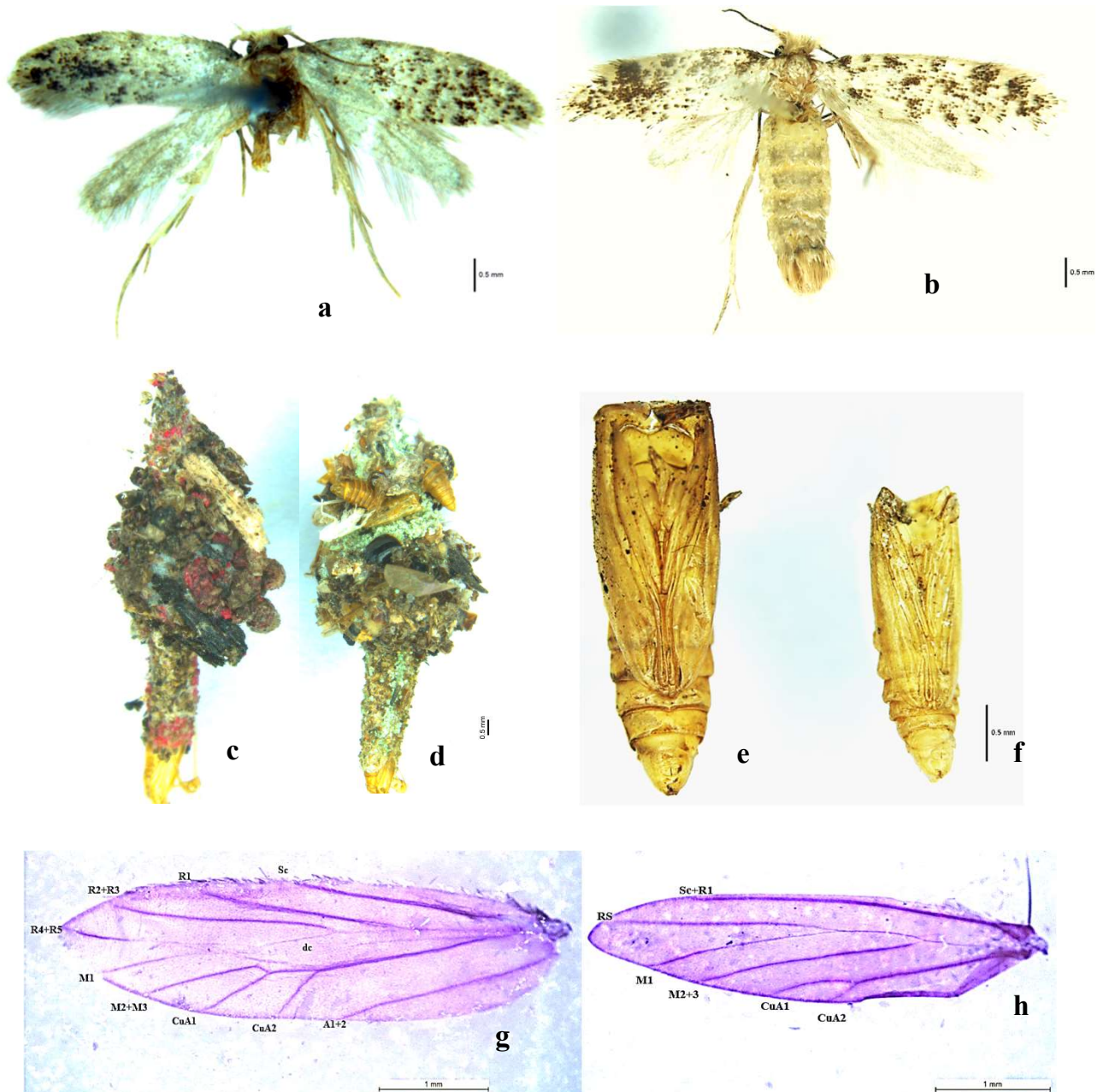
Pteroma plagiophleps Hampson, 1892



Figures: a. Adult moth male, b. Adult female . c. Larva and bag, d. Forewing venation, e. Hindwing venation, f. Genitalia male dorsal view, g. Larva.

PLATE 14

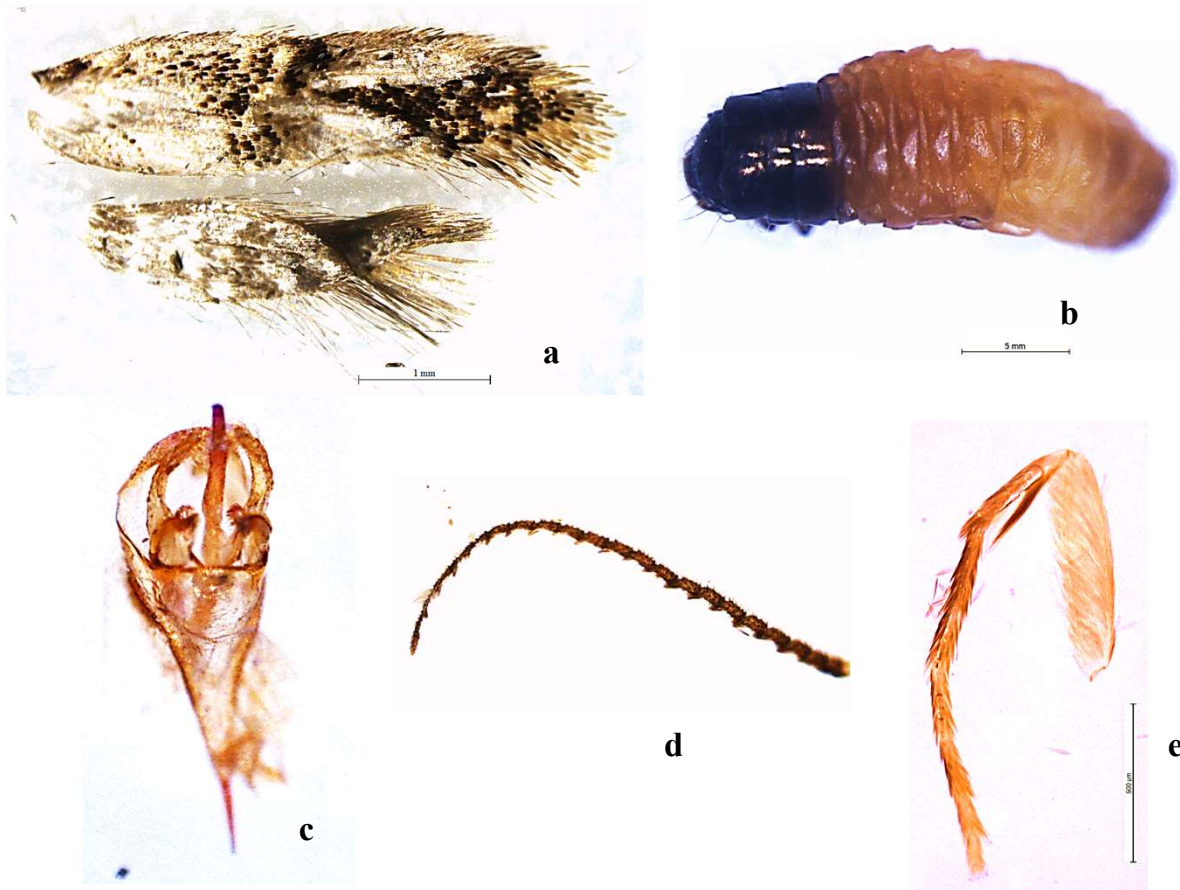
Eumasia thomasii Usha et al., 2022



Figures: a. Holotype: male, b. Paratype female . c. Female pupal bag d. Male pupal bag, e. Female pupal exuvia f. Male pupal exuvia, g. Forewing venation male, h. Hindwing venation male

PLATE 15

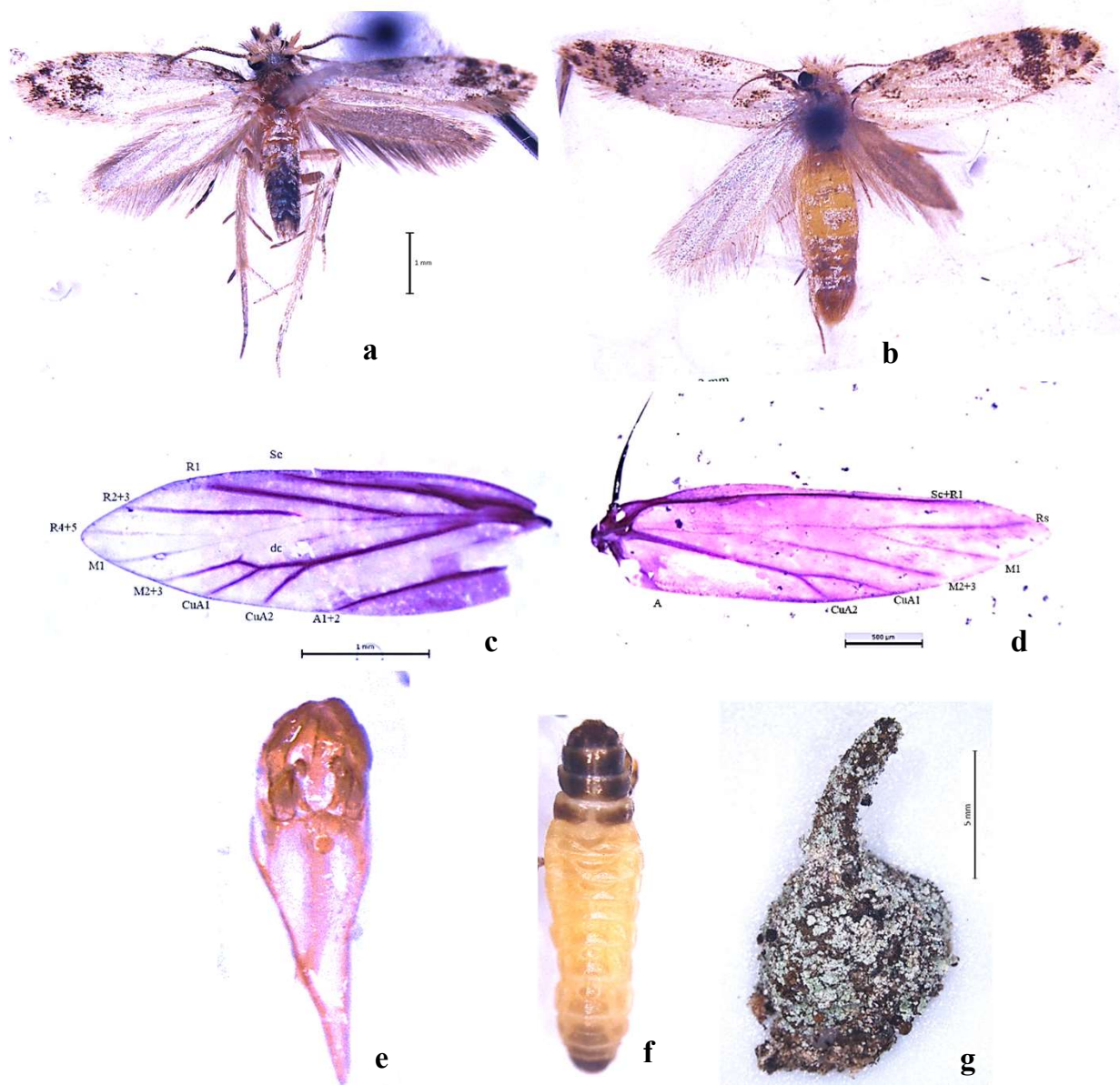
Eumasia thomasi Usha *et al.*, 2022



Figures: **a.** Forewing and Hindwing, female **b.** Larva. **c.** Genitalia male, **d.** Antenna male, **e.** Foreleg with hairbrush male.

PLATE 16

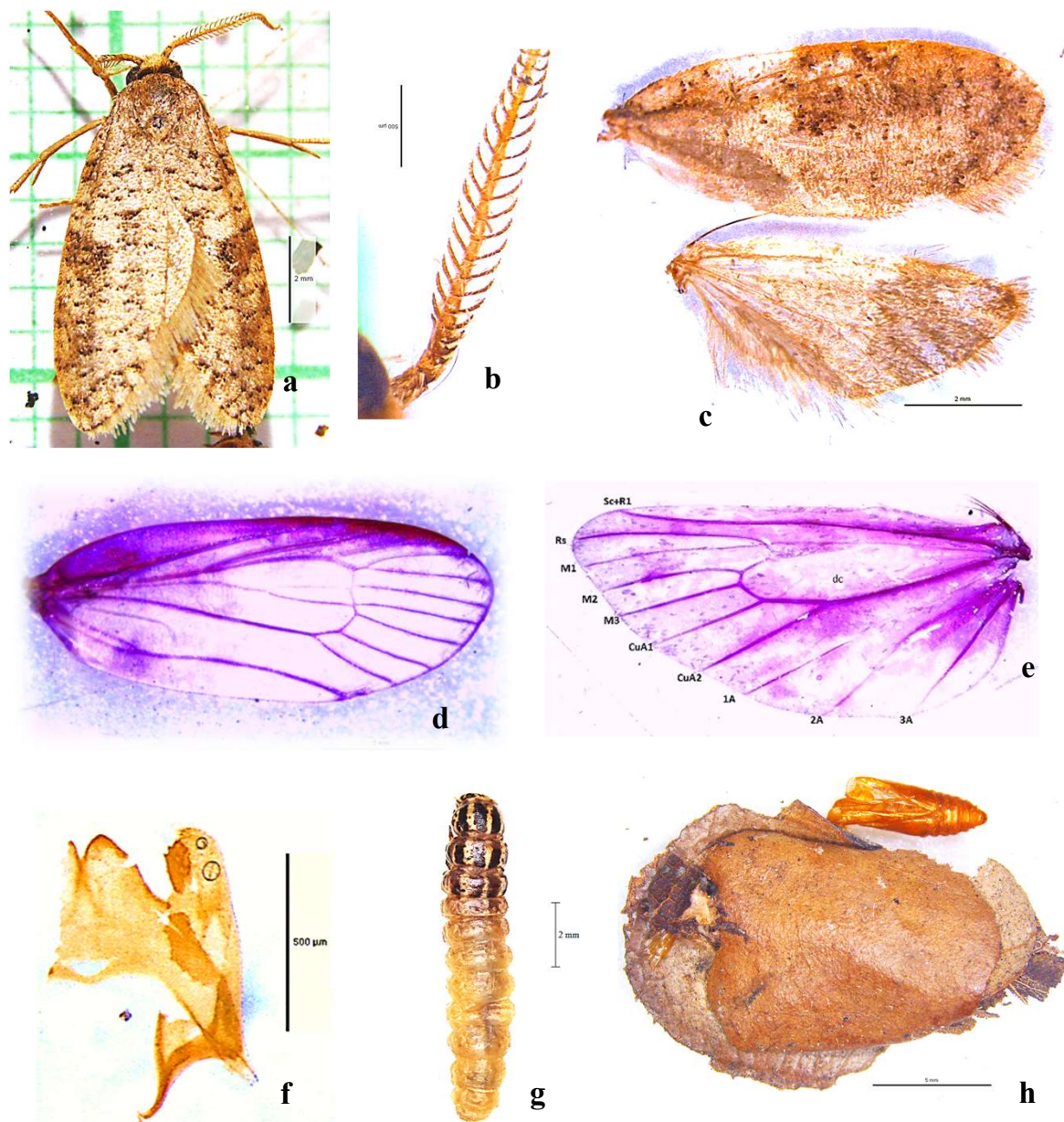
Eumasia venefica sp. nov



Figures: **a.** Holotype: male, **b.** Paratype female . **c.** Forewing venation male **d.** Hindwing venation male, **e.** Genitalia male **f.** Larva, **g.** Male pupal bag.

PLATE 17

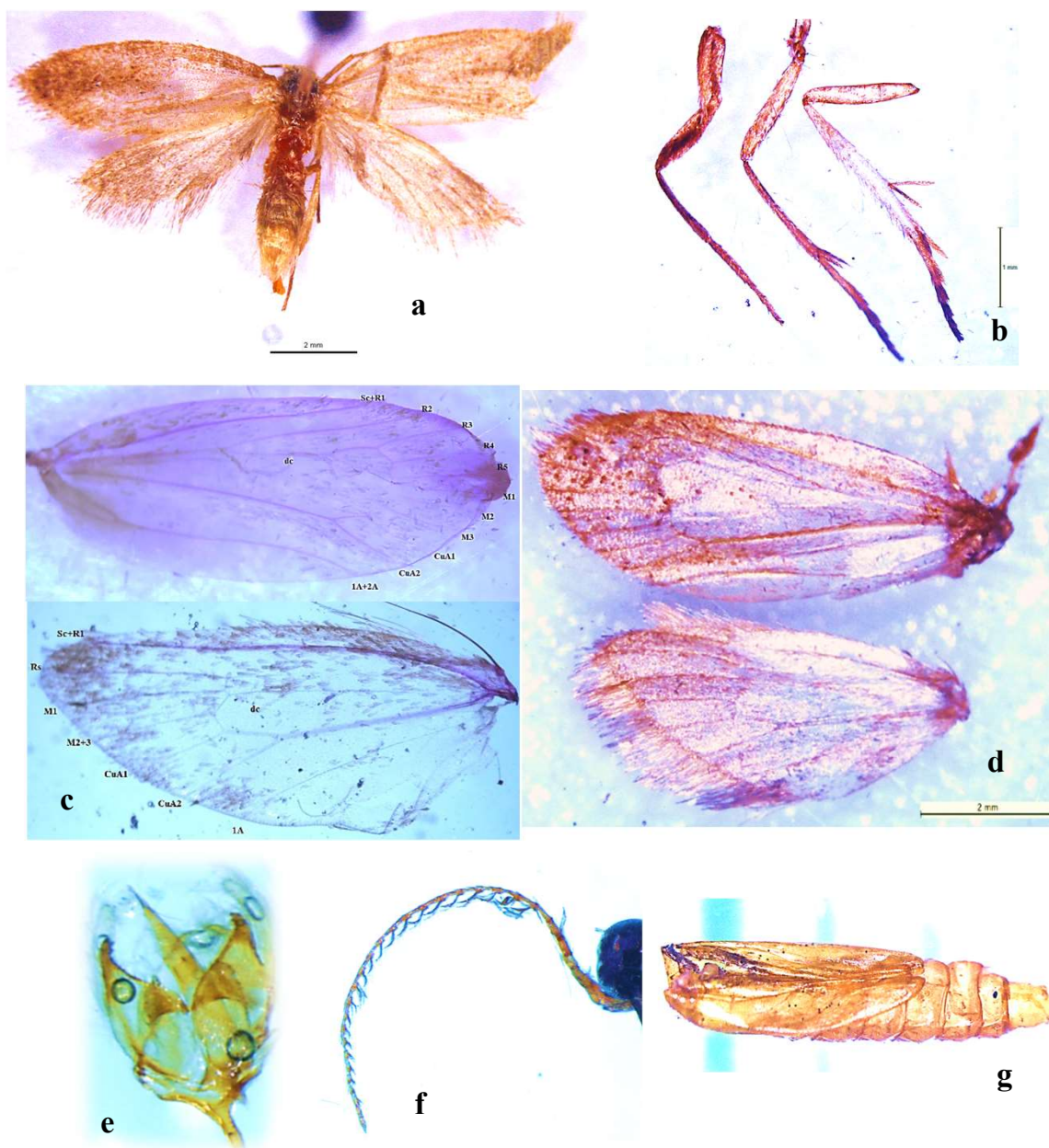
Degiella sp. nov.



Figures: **a.** Adult moth male, **b.** Antenna male. **c.** Forewing and hindwing male, **d.** Forewing venation, **e.** Hindwing venation, **f.** Genitalia male dorsal view, **g.** Larva, **h.** Male pupal bag with pupal exuvia.

PLATE 18

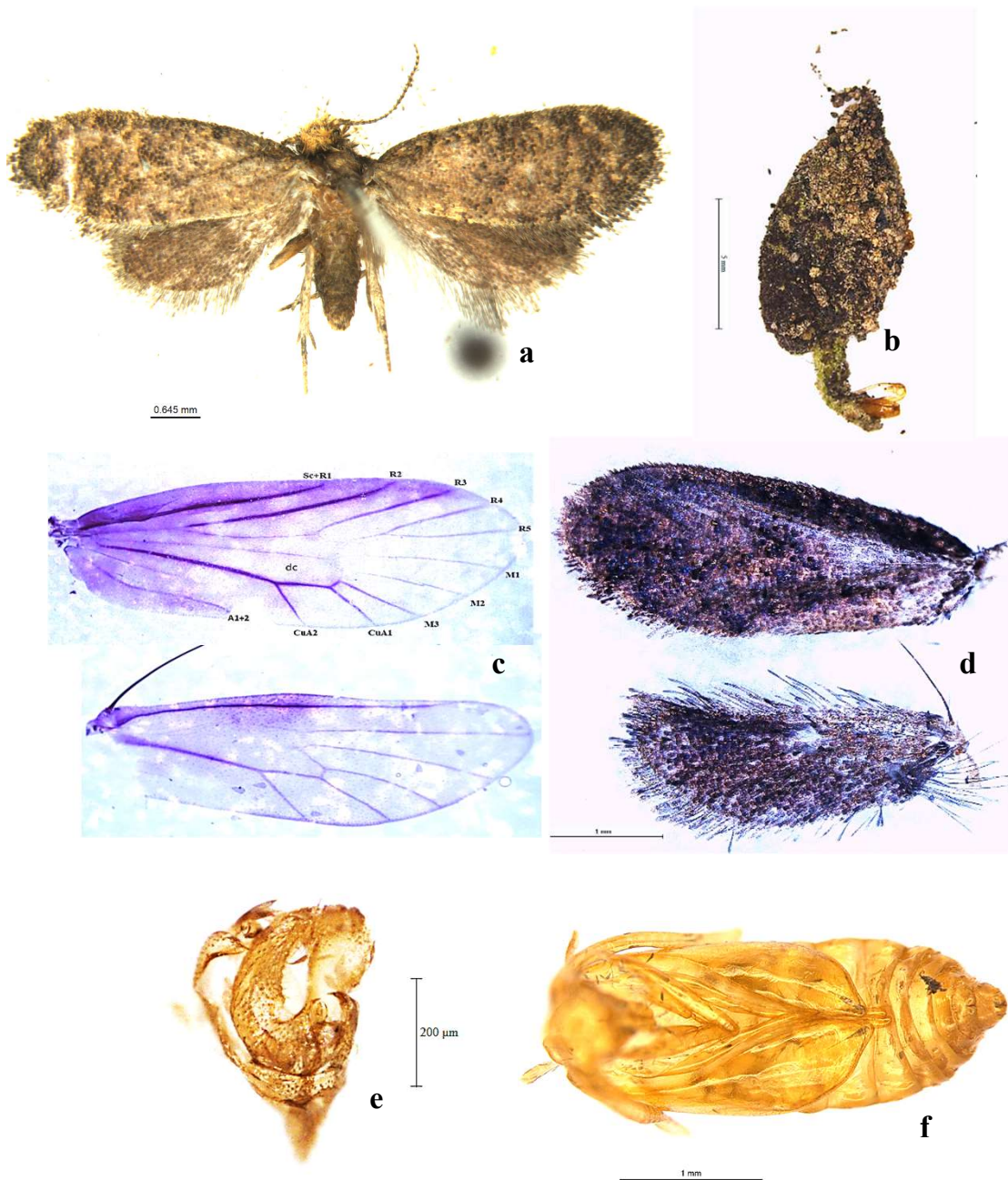
Struthisca cf farinosa Meyrick, 1919



Figures: **a.** Adult moth male, **b.** Male thoracic legs, **c.** Forewing and hindwing venation male, **d.** Forewing and hindwing male, **e.** Genitalia male dorsal view, **f.** Antenna male, **g.** Male pupal exuvia

PLATE 19

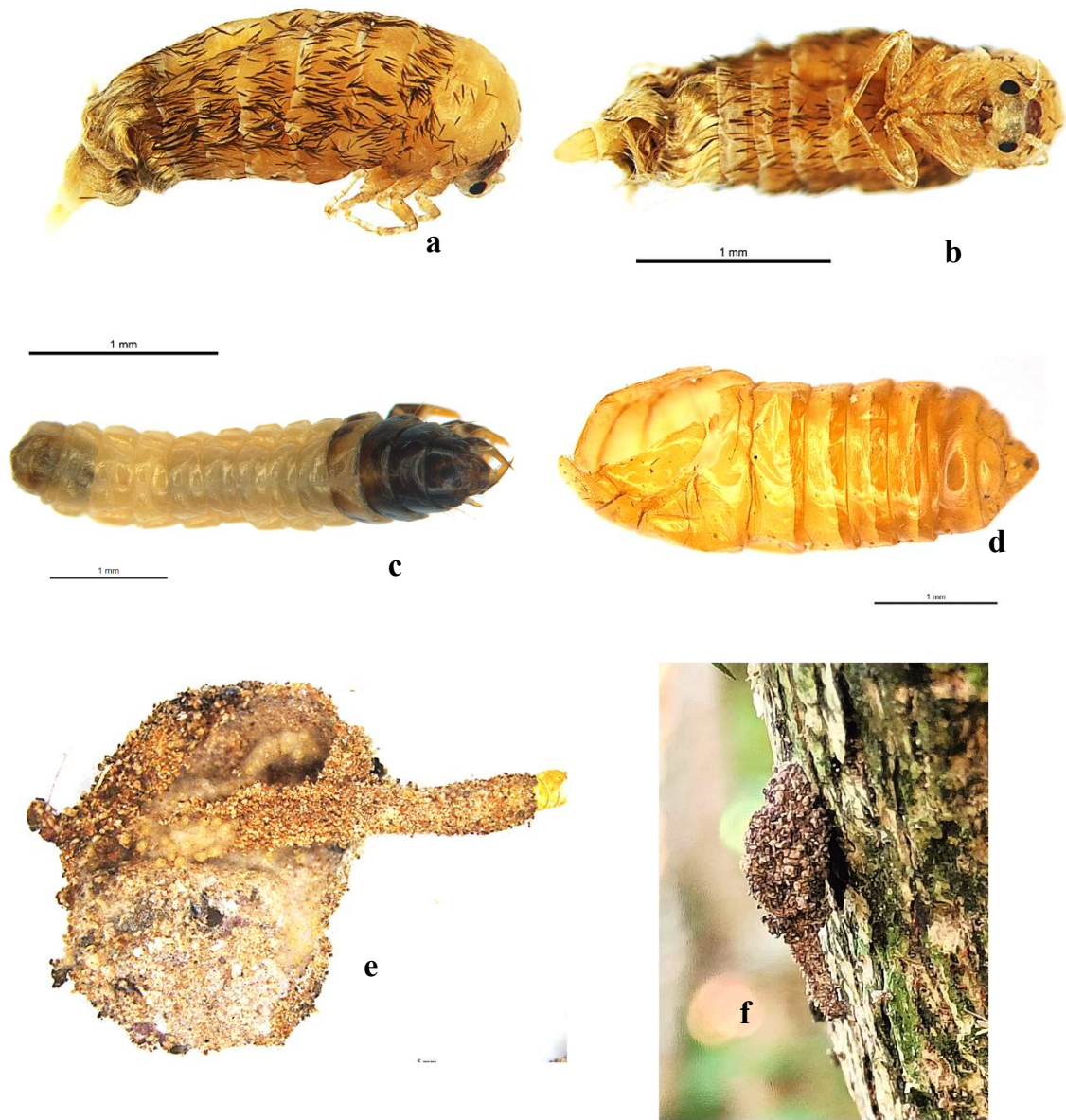
Capulopsyche keralensis Usha *et al.*, 2023



Figures: a. Holotype, Adult moth male, b. Male pupal bag with pupal exuvia, c. Forewing and hindwing venation male, d. Forewing and hindwing male, e. Genitalia male dorsal view, f. Male pupal exuvia

PLATE 20

Capulopsyche keralensis Usha *et al.*, 2023



Figures: **a.** Paratype: Adult female lateral view, **b.** Paratype: Adult female ventral view, **c.** Larva **d.** Female pupal exuvia , **e.** Female pupal bag cut opened, **f.** larva on the tree bark

CHAPTER 4

Bag architecture studies of bagworm species

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4.1. Introduction

Animals employ a variety of defenses against predators. Some of these techniques utilize environmental components as protective armour (Edmunds, 1974). The larval instars of many holometabolous insects have a variety of protective armour to save their delicate bodies (Greeney *et al.*, 2012). Root & Messina (1983) document three holometabolous insect orders - Trichoptera, Coleoptera and Lepidoptera using their own silk fibre, feces, and/or surrounding elements, to build "portable casings".

A conspicuous characteristic of bagworm moths is the ability of their larvae to construct portable cases (Rhainds *et al.*, 2009) generally referred to as bags or larval cases. Sugimoto (2019 a,b) has documented the use of different materials (tree/herb/grass leaves, lichens, twigs, petioles, bark fragments, wood debris) and sand particles by different species of bagworm. The protective role of portable bags is debated with some works supporting it (Rhainds *et al.*, 2009; Cronin & Gill, 1989) and other reports opposing it (Hawkins, 1994). Many bagworm species are polyphagous and are defoliating pests of cultivated crops causing severe to moderate damage. As the females of many Psychidae species complete their life cycle inside the bags and the number of males is very less when compared to females "*insects of this family are rarely seen on the wing, perhaps of a hundred cocoons that may be preserved in a breeding cage, only two or three males may be obtained*" (Watt, 1898).

Therefore, academicians let alone farmers are at a loss to identify many bagworm species in the field. In this scenario, it is very important to provide an identification tool to farmers to differentiate between bagworm moths (phytophagous) which can cause extensive damage and are harmless (lichen/moss/algae/omnivorous species). This chapter gives a comprehensive description of the larval bags of Psychidae from the study area and includes a preliminary identification key of the bagworm species of the region based on their larval cases.

4.2. Review of Literature

While there are many studies from across the globe that emphasize the morphology and economic importance of bagworm species, there are very few studies that concentrate exclusively on bag architecture and bag-making behaviour. The largest known larval bags in Psychidae are from the genus *Metura* (Beaver, 2020), the species *Metura aristocosma* is regarded as the species with the largest larval bag, it attaining more than 200 mm in length (Lower 1908; Common 1990).

4.2.1. Description of Bags:

Descriptions of larval and pupal bags of Psychidae were published in many of the previous works describing the taxonomy species in India (Watt, 1898, Watt & Mann, 1903, Hampson, 1910, Das, 1956) but detailed bag architecture studies are still lacking. Many species (*Acanthopsyche alstoni*, *Clania holmesi*, etc) were previously described based on the larval bags (Watt & Mann, 1903), as adult moths could not be collected.

Watt (1898) reported eleven species of bagworm moths from tea plantations in India, in which five species were described based on the larval bags only. In the second edition of this study Watt and Mann (1903) listed 14 species with six of them described only by larval bags. Das (1956) described 17 species of moths and their larval bags from tea plantations in North East India with detailed notes on their size and shape along with line drawings of the larval bags. He also listed two types of larval bags without adults. Sugimoto (2009 a) gave a detailed description of 11 Japanese Psychidae which included 2 undescribed ones. He also formulated a key for 30 Japanese Psychids based on the characters of the larval bags. Sobczyk 2015 while describing a new genus and species from Madagascar describes in detail the bags of *Mahasena poliotricha* Hampson, 1910: *Clania holmesi* Watt, 1898, *Mahasena tabrabana* Hampson 1910. Here all the larval bags have a spiral arrangement of sticks. A description based on the larval cases would no longer be possible and would be invalid according to ICZN rules (Usha *et al.*, 2022 a).

4.2.2 Bag making behaviour

Agrawal and Pati (1995) described the case-making behaviour of the bagworm *Eumeta crameri* in Chhattisgarh and mentioned the rhythmic pattern in the arrangement of sticks. Their study indicated that the bagworm larvae could process thorn length and

distance signals hierarchically, and by doing so, it maximizes time and energy while the larvae are still developing. They also studied larval case refurbishment and renovation as a behaviour of *Eumeta crameri* (Agrawal and Pati, 2003). In another study, they discussed how Dyar's law correlated with the length of the longest stick of *Eumeta crameri* by calculating Dyar's coefficient (Agrawal & Pati, 2002). The function of the protective case of the bagworms has been studied by using the species *Eumeta minuscula* and potential predator beetle *Calosoma maximoviczi* (Coleoptera: Carabidae), where the bagworm case was described as "portable armor" (Sugiura, 2016).

4.3. Methodology

4.3.1 Morphological study of the bags: The collected bags were classified according to the species and studies were done on their external and internal morphological characteristics, such as shape, the texture of bag material, extraneous materials, the ornamentation on bags, colour of each individual bag and the substratum for attachment. The dissections of empty bags were done to study the internal characteristics.

4.3.2 Morphometrics of Bags: The bag architecture was studied by using morphometric measures such as- length, width, angle of the bag attachment to the substratum, number of sticks, leaves, spots and measure of each stick (some parameters like angle of attachment, length of the sticks is applicable to some species only). A minimum of ten bags were measured and the average value was taken and tabulated. Micrographs/ photographs with scale were taken. The photograph was printed and traced using transparent grease proof paper. Details were added.

4.3.3 Explanation of terms used in the results:

a) Larval bag: Larvae renovate their bags at each instar. Almost all the larval bags of Psychidae have a basic conical shape. The larval head and thoracic legs protrude outside through the anterior opening and the fecal matter is discarded through the distal end or posterior opening. The larval bag architecture will be changing at each instar, so these stages are inappropriate for species confirmation.

b) Pupal bag: These bags are the final instar bags containing the pupal stage of the insect. The shape of the pupal bag is unique in each species. In this stage the shape of the bag becomes more stable so it is significant in species identification using bags.

c) Pupal exuvia: These are the pupal exoskeleton of the insect. All the male bagworm pupal exuvia are found attached to the distal end of the bag after the emergence of the moth. And the female insect which emerges as a moth also has a similar pupal exuvia attachment. But females with vermiform bodies and without appendages hide inside the bags and do not leave the bag. The pupal exuvia of the female insects remains inside the pupal bag and can be seen only by cutting open the pupal bag.

4.4 Results

Subfamily: Oiketicinae

1) *Acanthoecia larminati* Heylaerts, 1904 (Plate 22 a)

Materials examined: 10, 10.9142° N 76.2118° E, 10.5081° N, 76.2515° E, 10.3942° N 76.1410° E, Usha A U, Date: 10/12/2021, 24/01/2022, 09/04/2022, Hostplant: nil

The larval bags are long, conical, with smooth surfaces. The pupal bags are long cylindrical with both ends closed and tapering anterior and wide posterior ends (Fig.3). The bag has a smooth surface. The colour of the bags varies according to the habitat and materials used and is predominantly various shades of brownish grey and sometimes even orange-brown. There are no ornamentations on the surface of the bags except dark spots and markings in some bags. There are lighter shade markings around the centre and sometimes the posterior half of the bag which give the appearance of bands on the surface of some bags. Larval bags are conical in structure. The material of the bag is a mixture of plant debris, silk and dust.

Female pupal bags are a little larger than male bags. Pupal bags are found attached directly to the walls and leaf surfaces. The adult male bag length is 10 mm and width of 1 mm, 2 mm and 1 mm at the anterior, middle and posterior regions respectively. The adult female bag length is 12 mm and the width is 1.5 mm, 2.5 mm and 1 mm anterior, middle and posterior regions respectively.

2) *Acanthopsyche cana* Hampson, 1892 (Plate 22 c)

Materials examined: 05, 8.8731° N 76.8694° E, 11.2352° N 75.7938° E, 05/12/18, 29/10/2018, Usha A U, Hostplants: *Phyllanthus reticulatus* Poir, *Phyllanthus myrtifolius*.

The larval bag of this species is long and cylindrical in structure. The smooth silken bag is ornamented with many fragments of twigs on the entire surface. It gives the bag the appearance of being covered by many downward-pointed spikes (Fig.4). The materials used for bag making are from the host plants that they feed. Larva add small fragments of leaves and short sticks from the hostplants and pasted them on its surface in progressive instars. When the fresh layer of leaves is added, it appears like a green frilly collar around the anterior end of the bag. The adult male bag length is 25 mm and the width is 4 mm, 5 mm and 3 mm at anterior, middle and posterior regions respectively. The adult female bag length is 30 mm and width are 5 mm, 4 mm and 3.5 mm anterior, middle and posterior regions respectively. The bag is ornamented with an average number of 60-80 small sticks with variable lengths of 5 to 2 mm. The pupal bags are directly attached anteriorly to the hard substratum (bark of trees, walls) with a disc-shaped structure formed by the insect silk.

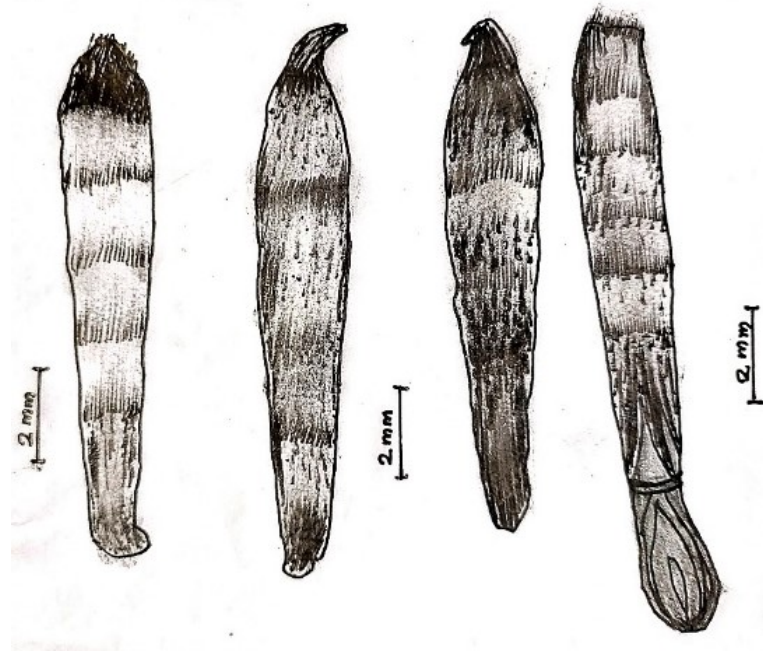


Figure 3: Drawing of bag of *Acanthoecia larminati*

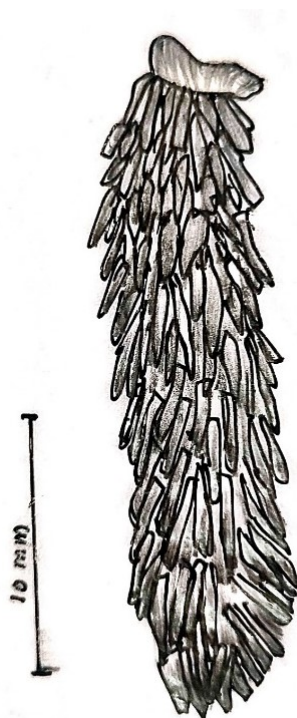


Figure 4: Drawing of bag of *Acanthopsyche cana*

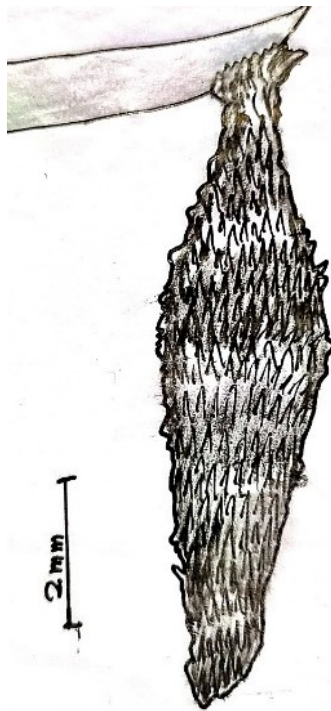


Figure 5: Drawing of bag of *Acanthopsyche alstoni*



Figure 6: Drawing of bag of *Acanthopsyche* sp

3) *Acanthopsyche alstoni* Watt & Mann, 1903 (Plate 22 b)

Materials examined: 10, 10.9142° N 76.2118° E, 9.8584° N 76.9528° E, Usha A U,

Hostplants: *Ficus benjamina*, *Madhuca neriifolia*

The larval bags are tiny and conical in shape. Adult bags are almost cylindrical with both ends closed and many numerous tiny spikes are present on the surface which are seen upon close inspection. It gives the surface of the bags a prickly appearance (Fig.5). The spiky appearance is due to the various materials such as, plant parts and bark tissues in addition to the silk. Adult male bags are 8.5 and 9.5 mm in length (2.1 mm wide at the centre). Adult female bags are about 11–12.5 mm in length, slightly longer and wider than males (2.8 mm wide centre). The pupal bags are attached permanently to the underside of leaves and another hard substratum. Silken threads are seen while the bags are being pulled away from the leaves. The thread stands out when it detaches or later due to weathering. (Usha *et al.*, 2022a).

4) *Acanthopsyche sp.* Hampson, 1892 (Plate 22 d)

Materials examined: 05, 11.2352° N 75.7938° E, 10.6645° N 76.2515° E, 10.5300° N 76.1952° E, 05/12/18, 29/10/2018, Usha A U, Hostplants: *Phyllanthus reticulatus*,

Phyllanthus myrtifolius

The larval bag looks like a long cylindrical tube. The circumference of the tube progressively decreases from the anterior end to the posterior and the bag ends as a tapering cone at the posterior end. The bag has a very hard and thick outer covering and is made up of closely packed silk and plant particles from its host plants. The surface of the bag is smooth and the ornamentation with small twigs is seen on the anterior or both anterior and posterior regions of the bags (Fig.6). The middle region is plain without any ornamentations. The larvae actively feed on the plants and build bags. The pupal bags are almost cylindrical and directly attach to the tree bark, and walls using a small disc-like silken segment. The adult male bag length is 28-30 mm and the width is 4.5 mm, 4 mm and 3 mm at the anterior, middle and posterior regions respectively. The adult female bag length is 33-35 mm and the width is 6 mm, 5.5 mm and 4 mm at the anterior, middle and posterior regions respectively.

5) *Clania holmesi* incertae sedis Watt 1898 (Plate 23 b, d)

Materials examined: 05, 11.9233° N 75.3126° E, 05/10/2022, Usha A U, Hostplants: *Casuarina equisetifolia*, *Phyllanthus emblica*

The larval bag of this species is very peculiar. It is in the form of a cylinder formed by small twigs arranged spirally on a base silk bag (Fig.7). An adult male larval bag is 16-17 mm in length. The entire male bag consists of four spiral arrangements and each spiral arrangement contains almost equal-length twigs; larvae make bags by using very small twigs from their host plants. The length of twigs used for each spiral arrangement progressively increases from the posterior to the anterior region of the bag. The different materials used are sticks of varying length and width, fragments of bark, leaf, etc. The width of each stick or used material has no specific range while the measurement the length of the sticks is much more constant than the width.

Female bags are comparatively bigger than males, it contains more sticks and 5 spiral turns and are wider than male bags. Male and female bags have lengths of 16-17 mm and 17- 19 mm respectively. The posterior end of the bag usually has bits of leaves and other plant parts instead of long sticks. The number of sticks in each turn varies according to the width of each stick but the length of the sticks is almost constant in each spiral turn. In the male bags, the number of sticks varies from 24-40, and in female bags, the number of sticks range from 45-80. The anterior diameter of each bag is 3-4 mm. The pupal bag is attached to the twigs of the hostplant with an angle of 125°.

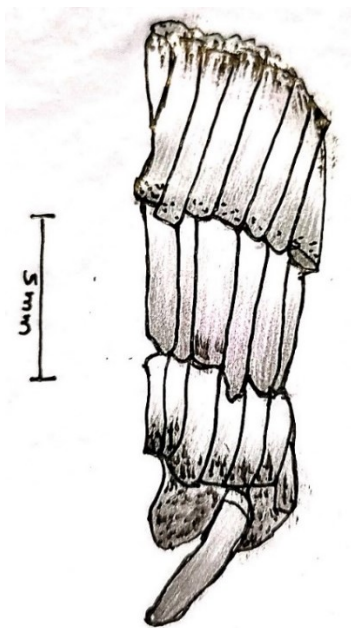


Figure 7: Drawing of bag of *Clania holmesi* (incertae sedis)

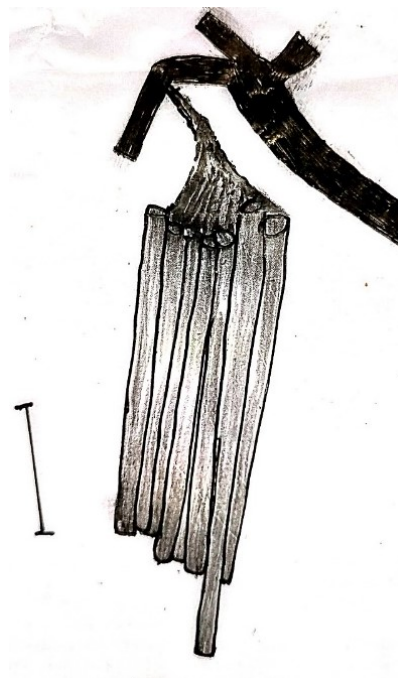


Figure 8: Drawing of bag of *Eumeta crameri*



Figure 9: Drawing of bag of *Eumeta variegata*

6) *Eumeta crameri* Westwood, 1854 (Plate 22 e)

Materials examined: 10, 10.1738° N 76.6008° E, 10.7288° N 76.6658° E, 15/05/2018, 30/05/2017 Usha A U, Hostplant: *Phyllanthus emblica*, *Casuarina equisetifolia*, *Terminalia catappa*, *Tamarindus indica*

The larval bag of this species is cylindrical externally, made by attaching twigs from the host plants in a circular pattern and most of the bags show a common characteristic of possessing a proportionately longest stick (Agrawal and Pati, 1995, 2003). The colour of the bags depends on the colour of the twigs and ranges from greenish grey to dark brown. The sticks are attached on a spindle shape tough silky bag around their body using silk threads (Fig.8). The silk bag is whitish cream coloured and has two openings at the anterior and posterior ends (Usha *et al*, 2021). The mean measurements

of a male pupal bag are length 45 mm; width of 10mm, 11 mm and 8 mm at anterior, middle and posterior regions; 30 mm in circumference and an outer diameter of 9 mm. Our observations concurred with earlier studies in North and South India (Agrawal & Pati, 1995, 2003; Usha *et al*, 2021). During pupation, the pupal bags are attached to twigs, branches of trees, the underside of leaves, walls, and bark.

7) *Eumeta variegata* Snellen, 1879 (Plate 22 f)

Materials examined: 04, 11.2587° N 75.7803° E, 12.1197° N 75.3189° E, Usha A U,
Hostplant: *Phyllanthus emblica*, *Casuarina equisetifolia*

Larval bags of this species are long, cylindrical in shape and made up of silken threads, fragments of leaf, twigs, and bark. Pupal bags are spindle-shaped with both tapering ends and ornamented with very long sticks extending their bag length (Fig.9). The bags of younger larvae are conical and covered with small leaf fragments from the hostplants. The surface of the adult bagworm bags is ornamented with medium to long twigs and leaves. In some bags, an entire compound leaf was seen attached as ornamentation. Bags of adult females are longer and wider than males. The adult male bag length is 38 mm and width are 7 mm, 10 mm and 6 mm at the anterior, middle and posterior regions respectively. The adult female bag length is 45 mm and the width is 8 mm, 13 mm and 9 mm at the anterior, middle and posterior regions respectively. The composition and structure of bags are similar in both sexes except for size. The larval bags are attached directly to the hostplant with strong binding of the silken threads during pupation. Sometimes they use the larval bag of another species of bagworm for their bag building and attach it to their bags. This kind of fused bag attachment was seen in the bags of bagworms collected from Malappuram.

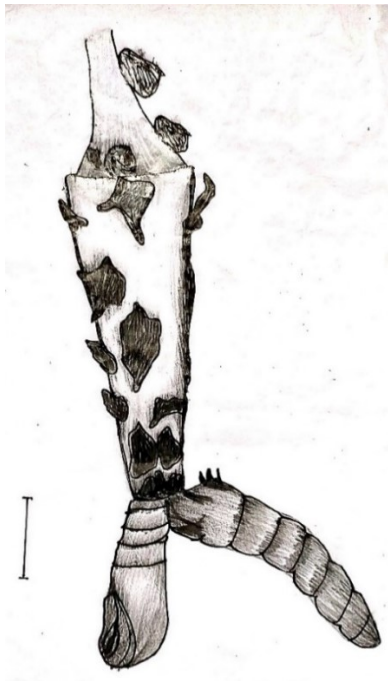


Figure 10: Drawing of bag of *Manatha albipes*

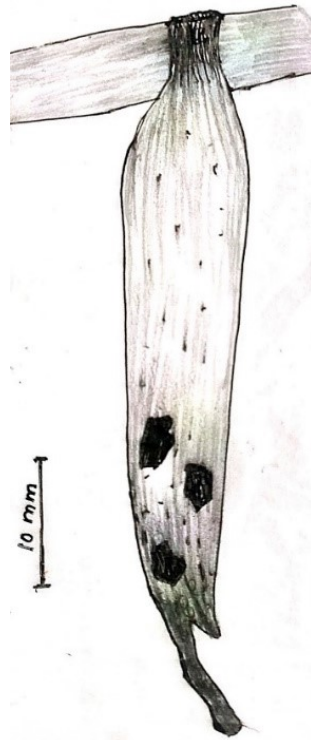


Figure 11: Drawing of bag of Unidentified sp. 1



Figure 12: Drawing of bag of Unidentified sp. 3

8) ***Manatha albipes*** Moore, 1877 (Plate 23 a)

Materials examined: 06, 10.4751° N 76.3345° E, 10.3149° N 76.1313° E, 28/05/17, Usha A U, Hostplant: *Pongamia pinnata*, *Cassia fistula*

The larval bag of this species is whitish cream colour, cone-shaped and covered with pieces of thin bark or bits of leaves, the moulted head capsules of the larval instar are attached around the bag. The larval bags are made of silk, leaf fragments and bark. From the lower end of the bag of a last instar, protrudes an empty pupal exuvia from which the male insect has escaped (Fig.10). A mature male larval bag measures about 18-20 mm (including the anterior web-like region) and has an anterior, middle and posterior width of 6mm, 5mm and 3 mm respectively. The outer diameter is 6.04mm at the anterior end and 3.3mm at the posterior end.

Female bags are almost cylindrical and compared to male bags they are longer and wider in size. A mature female bag length is 21- 25mm and anterior, middle and posterior widths are 6.5mm, 6 mm and 4 mm respectively. The pupal exuvia of the female is 15 mm in length and found inside the female bag (Usha *et al.*, 2022). The pupal bags are found attached to the branches of trees, the underside of leaves and hard surfaces with a small thread like portion of the bag.

9) Unidentified sp. 1 (Plate 25 a,b)

Materials examined: 10, 12.5279° N 74.9685° E, Usha A U, Hostplants: *Cocos nucifera*, *Casuarina equisetifolia*

The larval bag of this species is a long conical appearance with a tapering distal end. The bags are whitish and have an almost plain surface, sometimes ornamented with several bits of leaves and other plant parts mostly concentrated on the lower and middle region of the bag (Fig.11). A small thread-like bag extension at the posterior end is seen in the bags. Female bags are larger than males. An adult male bag has 40 mm in length including a short extension at the posterior end and width is 7 mm and 5mm at anterior and posterior regions., The adult female bag is 55 mm in length including an extension and width is 9 mm and 6 mm in anterior and posterior regions. The pupal bags are directly attached to the plants by a strong attachment with silken threads, the attachments are seen on the twigs and underside of the leaves of plants and trees. The larvae are polyphagous, feeding plant leaves and shoots making severe damage to the host.

10) Unidentified sp. 2 (Plate 25 c)

Materials examined: 05, 11.2352° N 75.7938° E, 05/12/2018, Usha A U, Hostplant: *Ixora coccinea*

The larval bags are long cone-shaped ornamented with round-shaped pieces of leaves around the bag, this arrangement is seen throughout the length of the bag which gives the bag an appearance of a flower from the anterior view. The larvae actively feed on the upper surface of the plants and make holes and cause damage. The length of a larval bag is 12 mm and 4 mm in width.

11) Unidentified sp. 3 (Plate 25 d)

Materials examined: 05, 11.2587° N 75.7803° E, 18/05/2023, Usha A U, Hostplant: nil

Larval bags are blackish and tubular with slight bending on the anterior portion and tapering posterior apex giving a “horn” shaped appearance to the bags (Fig.12). The bag surface is almost smooth without any ornamentations and the bag has a blackish spotted appearance on the surface with fragments of plant parts. A white colour band is present on the collar region of some bags. A larval bag has a maximum of 14-16 mm length and 3.5 mm anterior width and 1.5 posterior width. The larval bags are always

seen attached to the bark regions of the trees and the larva build bags from the bark tissues and silk. The pupal bags of this species were not obtained.

12) Unidentified sp. 4 (Plate 25 e)

Materials examined: 04, 11.7780° N 75.4694° E, 22/03/2018, Usha A U, Hostplant: *Terminalia catappa*

Larval bags are tough and conical-shaped with smooth surfaces. Larvae are actively feeding on the plant leaves and making severe damage. Larvae make strong bags with silken threads and plant materials. The pupal bags are long and cylindrical in structure with a tapering posterior end and wide anterior region (Fig.13). They are attached to the underside of the leaves and branches during pupation with a thread-like extension of the bag. The larval bag length is between 15-20 mm.

13) Unidentified sp. 5 (Plate 25 f)

Materials examined: 02, 11.2587° N 75.7803° E, 9.3222° N 76.3840° E, Usha A U, Hostplant: Nil

The larval bags are cone-shaped and ornamented with various types of materials on their surface. The larvae build bags using different available materials from the surroundings and the bags are looking like moving debris boxes (Fig.14). Larvae actively feed on plants and flowers. The materials on the bag surface include long and short sticks, thorns, leaves, flower parts, plastic, snail shell, feathers of birds, soil and small stones. A larval bag has 9.6 mm in length and width of 1.7 mm, 3.5 mm, and 2 mm at anterior, middle and posterior regions respectively.

14) Unidentified sp. 6 (Plate 26 a)

Materials examined: 02, 9.6706° N 76.5579° E, Usha A U, Hostplant: *Cocos nucifera*

The larval bags are conical in shape. The surface is pasted with leaf fragments (Fig.15). These bags are collected from the leaves of the coconut tree and the larvae actively feed on its leaves. Bags are ornamented with random-shaped fragments of hostplant leaves and pasted on the surface of the bags and other materials like small sticks, and bark tissues are also present on the bags. A larval bag measures 13.7 mm in length and is 4 mm and 1.8 mm wide at the anterior and posterior ends. Its larval length is 7.7 mm. The larval bags are seen attached to the underside of the leaves.



Figure 13: Drawing of bag of Unidentified sp. 4



Figure 14: Drawing of bag of Unidentified sp. 5

x

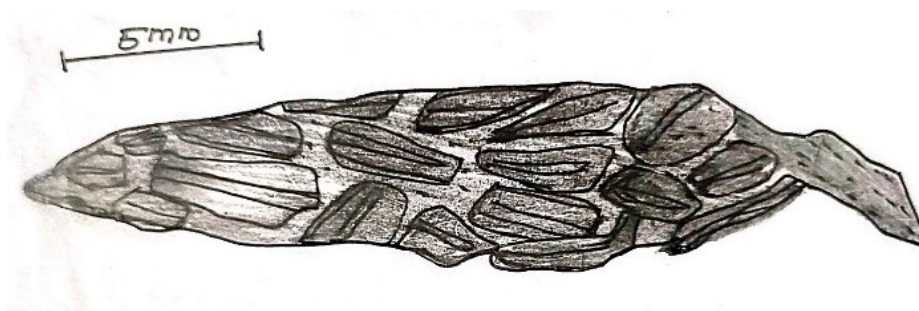


Figure 15: Drawing of bag of Unidentified sp. 6

15) Unidentified sp. 7 (Plate 26 b)

Materials examined: 02, 9.3610° N 76.4001° E, Usha A U, Hostplant: *Lagerstroemia speciosa*

The larval bags of species are very long and conical in shape with wide anterior and tapering posterior ends. There is a disc-shaped folding seen at the anterior opening. It is clearly visible in the pupal bags than in larval bags. The larvae feed actively on the leaves and make holes in them. Severe attacks by these larvae have been recorded in the study areas. The pupal bags are attached with a long thread with the substratum and

they have been seen on the bark, twigs, underside of leaves and walls. A mature larval bag is about 15 -17 mm long, and width at the anterior and posterior ends are 2.7 mm and 1.5 mm respectively. The larvae are very long with a length of 11 mm. The total diameter of the anterior fold is 3.5 mm and its inner opening has a diameter of 1.8 mm.

16) *Metisa canifrons* Hampson, 1910 (Plate 23 c)

Materials examined: 10, 11.1557° N 75.8912° E, 9.8584° N 76.9528° E, 13/03/2019, Usha A U, Hostplant: *Phyllanthus emblica*

The larval bag is whitish cream, long cylindrical in shape with a smooth surface. Randomly arranged small round leaf fragments pasted on the surface gives a dotted appearance (Fig.16). Female bags are larger than male. A thread is connected to the anterior region of the bag to the substratum during the time of pupation. The thread has a varying length of 11-23 mm. An adult male pupal bag is 15 mm in length and has a width of 3.5 mm, 3mm and 2 mm at the anterior, middle and posterior regions respectively. The female pupal bag is 25 mm in length and has a width of 4 mm, 3.5 mm and 3 mm in in anterior, middle and posterior regions respectively. The angle between the substratum and the attachment thread ranges between 40-48°. The thread inclines with the anterior portion of the bag and has an angle with the central axis that varies between 40-120°. Pupal bags are attached to the underside of the leaves and other hard substratum.

17) *Metisa plana* Walker, 1883 (Plate 23 e)

Materials examined: 10, 11.2587° N 75.7803° E, 10.3120° N 76.1325° E, 06/01/2018, 19/04/21, Hostplant: nil

The larval bag is made up of silk and hostplant particles such as leaves, small twigs and grass. The bag of young larvae looks conical while moving, and the round and rectangular-shaped pieces of plant materials are randomly placed in the surroundings of the anterior opening of the bag. During the progressing instars, the larvae increase their bag's length and width according to their body size, adding extra pieces of leaves and pasting them on the surface of the bag giving the surface a smooth appearance. At the last instar, the shape of the bag will be almost spindle-shaped with the tapering anterior end broader than the posterior end (Fig.17).

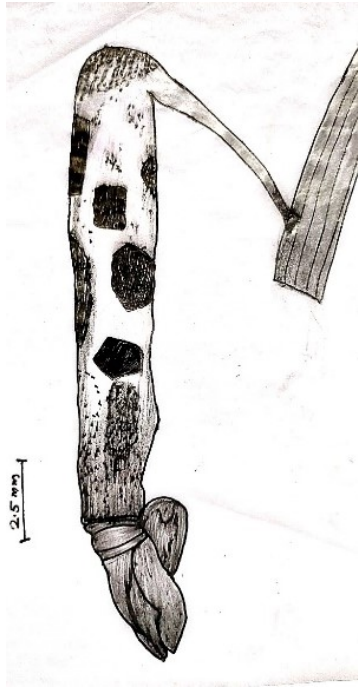


Figure 16: Drawing of bag of *Metisa canifrons*

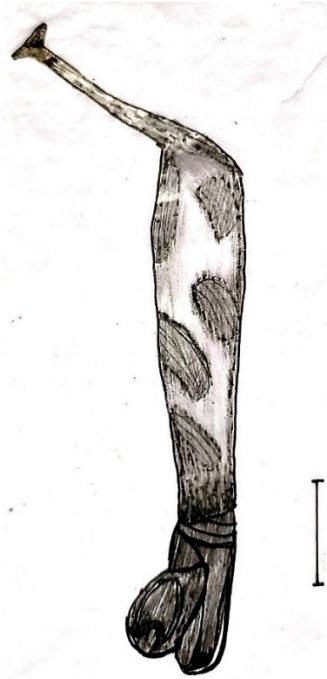


Figure 17: Drawing of bag of *Metisa plana*

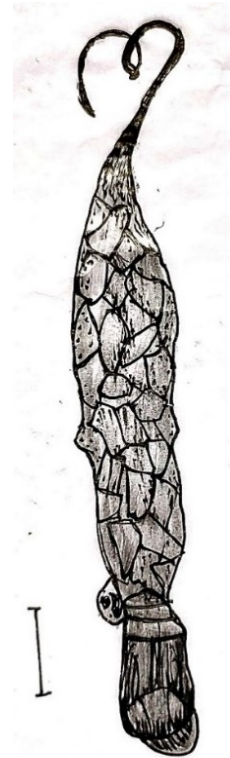


Figure 18: Drawing of bag of *Pteroma plagiophleps*

At the time of pupation, bags are attached with a small thread to the substratum, mainly the underside of the leaves and under the surface of walls as groups with many individuals. The length of a connecting thread is 6-10 mm. The pupal bags are connected to the substratum with an inclination, and the angle of the attachment of the bag is between $20^{\circ} - 32^{\circ}$. There is another inclination between the central axis of the bag and the thread, this angle is between $100^{\circ} - 130^{\circ}$. The pupal bag of male and female insects is different in size with female bags being larger compared to males. The pupal bag of female has a length of 16 mm and width of 3 mm, 4 mm and 2.5 mm at the anterior, middle and posterior region respectively. Male pupal bags have a length of 13 mm and width of 2 mm, 2.5 mm and 1.5 mm at the anterior, middle and posterior regions respectively.

18) *Pteroma plagiophleps* Hampson, 1892 (Plate 23 f)

Materials examined: 10, 10.4575° N 76.1523° E, 10.4420° N 76.2183° E, 21/04/2017, 01/01/2018, Usha A U, *Phyllanthus emblica*, *Delonix regia*

A relatively small-sized bag, the larval bags are almost conical in shape. The bag surface is almost smooth and made of woven insect silk and the surface is sparsely covered with fragments of leaves, small twigs, etc. The larvae cut the leaves into small pieces and paste them on the surface of their bag (Fig.18). The process continues till the last instar stage.

At the time of pupation, the pupal bags are attached to the substratum with a long thread, which is longer than the length of the larval bag and the shape is more spindle like with both tapering ends. The average length of the adult male bag is 12 mm long and width is 1 mm, 2.5 mm and 1.5 mm at anterior middle and posterior regions respectively. The adult female bag is 15 mm long and width are 1.5 mm, 3 mm and 2 mm at anterior middle and posterior regions respectively. The long thread in pupal bags has a variable length of 10-15 mm. Larvae feed actively feeding on the surface of the host plant leaves and make holes in the lamina. They inhabit as a large group on plants and can cause severe loss in their foliage.

Subfamily: Eumasiinae

19) *Eumasia thomasii* Usha *et al.*, 2022 (Plate 24 a)

Materials examined: 10, 10.1777° N 77.2538° E, 28/12/2021, Usha A U, Hostplant: nil

Larval bags of this species are round externally with a long tube protruding at the lower end. The tube extends upward internally as a long tube-like bag. It is wrapped with a sheath made up of silk, sand, soil particles, snail shell, algae, and other insect debris (Fig.19). All the bags are attached to the underside of the rocks with a small thread. Male larval bags are smaller than females and it has a length range of 8-11 mm and a width range of 3.5- 5 mm. Female larval bags are 11-13 mm long and 4.5 – 6 mm wide. The species that inhabited the rocks feed on algae and mosses on the rocks (Saigusa and Sugimoto 2013; Roh and Byun 2016, Roh *et al.* 2018). A similar composition was seen in the bags of this newly discovered species (Usha *et al.*, 2022 c).

20) *Eumasia venefica* Usha *et al.*, 2023 (Plate 24 b)

Materials examined: 10, 9.7424° N 77.0939° E, 08/10/2022, Usha A U, Hostplant: nil

The larval bag of this species has a ‘witches’ hat’ appearance, a disc-like anterior, and, a tubular posterior part (Fig.20). The adult bag has a maximum of 8-9 mm length, the disc-like anterior part has a diameter of 5 mm, 2 mm middle and 1-1.5-mm posterior width. The larvae and pupal bags are found on rocks covered by lichens. The larvae feed on lichens and ornament the bag with lichen parts. The pupal bags are found in large colonies in groups of more than ten bags during pupation, attaching to each other.



Figure 19: Drawing of bag of *Eumasia thomasii*

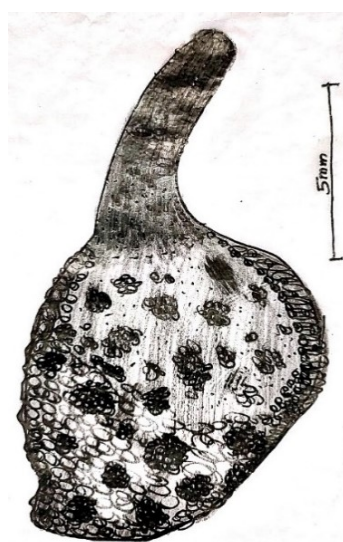


Figure 20: Drawing of bag of *Eumasia venefica*

21) *Eumasia* sp. (Plate 26 f)

Materials examined: 02, 9.7424° N 77.0939° E, 08/10/2022, Usha A U, Hostplant: nil

The external appearance of the larval bag of the species is almost conical and double-walled. An inner long tube-like bag wrapped with a sheath made up of lichen, soil, rock particles and silk. The cylindrical-shaped pupal bags were found hanging individually on rocks associated with lichens. The larva feeds lichen and other materials present on the rock. The inner larval bag has a length of 11-13 mm and the outer sheath 5-8 mm long and 2mm, 6mm, 25 mm of anterior, middle and posterior widths respectively.

Subfamily: Typhoniinae

22) *Degiella* sp nov. (Plate 24 d)

Materials examined: 10, 10.9142° N 76.2118° E, 9.9894° N, 76.5790°, 28/06/2022, 10/02/ 2023, Usha A U, Dr. Joyce Jose, Hostplant: nil

The larval bags of this species are made up of stacking the leaf pieces one above the other on both sides of a long silken bag (Fig.21). The width of the leaf pieces decreases towards the posterior end of the bag but the length of the leaf pieces is random. There is a maximum of 5 stacking layers of leaf pieces seen on each side of the bag, the top one piece has the maximum width, an average of 10 mm. The larvae build these bags with different types of materials like leaves, plastic covers, paper, and bark and pasted these materials on the surface of the silken bag. The female bags are larger in size than males and has variable lengths from different places, 20-30 mm and each stacking segment has a variable length. Male pupal bags are 18 mm long, and 9 mm, 12 mm and 5 mm wide at anterior, middle and posterior regions. Phytophagy was not observed in its larval stage. All collected larval and pupal bags were collected from the surface of the walls of buildings and the underside and edges of the compound walls with direct attachment.

23) *Struthisca* cf *farinosa* Meyrick, 1919 (Plate 24 c)

Materials examined: 10, 9.9894° N, 76.5790° E, 10.9142° N 76.2118° E, 28/06/2022, 10/02/ 2023, Usha A U, Dr. Joyce Jose, Hostplant: nil

The larval bags of this species are small, made up of small twigs arranged almost vertically on a long bag made of silk. The twigs are arranged randomly on the silky bag and there was no specific pattern in arrangements were observed (Fig.22). An individual bag contains about 5- 10 sticks of various lengths on the surface of the bag. The larval bags resemble the bag of *Psyche casta*. The larval bags of *Struthisca* cf *farinosa* are found on the rocks and compound walls near the grasslands. The sticks of grasses, small twigs and leaf fragments are usually used to build the bags. The larvae feed grasses and other plant materials. The adult bags are different in size, female bag measures a maximum length of 15 mm including the length of the longest stick pasted on its surface Width was 2 mm, 3.5 mm and 2-mm at anterior, middle- and posterior regions. Male bag has a maximum 12 mm length and 1.5 mm anterior and 2.5 mm posterior width.

24) Unidentified sp. 8 (Plate 26 d)

Materials examined: 02, 10.0630° N 76.3003° E, 23/06/2019, Usha A U, Hostplant: nil
The larval bags are long and triangular with three sides and sharp vertices. Each bag has a triangular-shaped anterior opening and tapering posterior end. The length of the adult bags ranges from 15-20 mm. Each side of the bag has similar width which increases according to the length. A bag with 20 mm length has sides of 3 mm width anteriorly. The larvae are found on moist surfaces where algae and mosses grow. The surface of the bags has a smooth appearance and has no ornamentations. The anterior region of the bag has a slight forward bent and the posterior end is loosened and splits the bag as three parts. The pupal bags are attached to the surface of walls by direct attachment with silken threads.

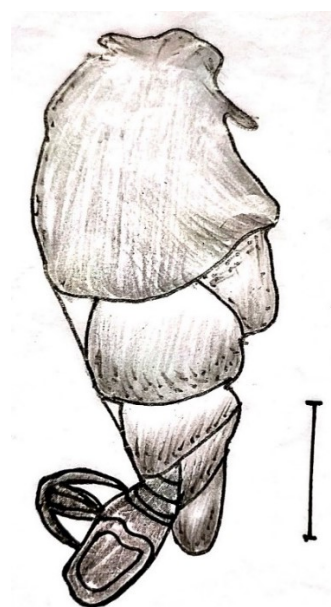


Figure 21: Drawing of bag of *Degiella* sp. nov., Sobczyk, 2009



Figure 22: Drawing of bag of *Struthisca* cf. *farinosa*, Meyrick, 1919

Subfamily: Taleporiinae

25) *Capulopsyche keralensis* Usha et al., 2023 (Plate 24 e,f)

Materials examined: 10, 9.7424° N 77.0939° E, 10.4793° N 76.7014° E, 08/10/2022, Usha A U, *Coffea arabica*

The larval bag of this species is an elongated tube, wrapped with a sheath made up of bark and other plant tissues (Fig.23) and hung up with a thread to the substratum. The pupal bags are seen attached to the tree branches and underside of the leaves. Double-walled larval bags are occasionally known in the Psychidae. Most similar are the triangular larval bags of *Diplodoma* Zeller, 1852. In this genus, the bags are also hung up on threads. The inner bag has a distinctive triangular shape and is not visible from the outside. The outer bag also has a triangular basic shape in cross-section (Usha *et al.*, 2023)

The larva makes its bag using silk, bark tissues and lower plants (lichens, algae, mosses) present on the bark. An adult male bag has a length of 13 mm and the outer sheath has 5 mm, 2 mm and 1.5 mm anterior, middle and posterior width. Female bag is 16 mm long and 2.7mm and 2.5 mm wide at anterior and posterior widths. Attachment thread of each bag is 7-9 mm long.

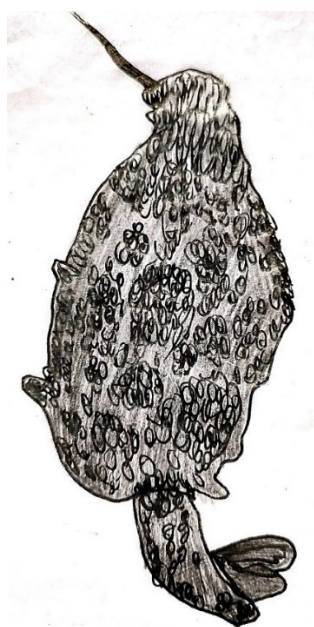


Figure 23: Drawing of bag of *Capulopsyche keralensis*

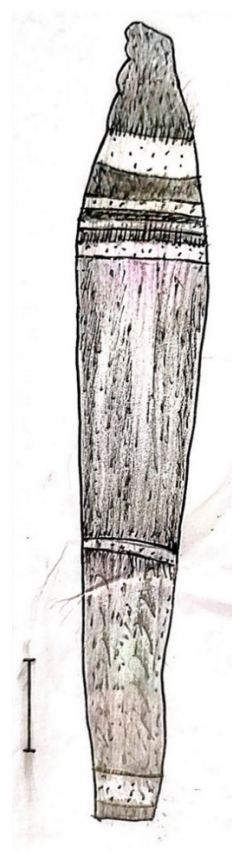


Figure 24: Drawing of bag of Unidentified sp. 9

Subfamily: Unknown

26) Unidentified sp. 9 (Plate 26 e)

Materials examined: 02, 9.7424° N 77.0939° E, 10.4793° N 76.7014° E, 09/10/2022,
Usha A U, Hostplant: nil

It is a peculiar type of larval bag found attached to the bark of trees associated with lichens. They are very long, tubular and reddish brown in colour similar to the colour of the bark of the host tree. The surface is always coated with lichen parts giving a greenish tinge. The surface of the bag is almost smooth without any other ornamentations (Fig.24). There is a light yellowish band-like appearance seen on the outer surface of the bags, which is seen randomly in different regions. Most of the bags are attached to the bark. Larvae feed by scraping on the bark of lichens and bark tissues. The larvae make the bag using silk, lichen and bark tissue. The size of the larvae is very small compared to the length of the bag. A larval bag has a length of 14 mm and has width of 0.8mm, 2mm and 1 mm in anterior, middle and posterior regions but the larval length is only 4.6 mm.

4.5.2 Key for the Identification of Bags

The identification keys for all the identified subfamilies and species are prepared based on the morphological and other unique characteristics of the pupal bags of the species. The bag sizes are categorized into large, medium and small based on the collected bags. Large bags ranges from 20-50 mm, medium bags ranges is less than 20 mm and more than 10mm and small bags are less than 10 mm in length.

4.5.2.1 Identification key to the 5 subfamilies, identified genera and species of different subfamilies

1. Large and medium -sized bags (20-50 mm) 2
- 1'. Medium or small-sized bags (medium bags ranges is less than 20 mm and more than 10mm and small bags are less than 10 mm in length.)10
2. Pupal bags connected with a small extension of the bag to the substratum.....Oiketicinae).....3
- 2'. Pupal bags connected with a long thread to the substratum.....(Metisinae).....8

3. Bags with rough surfaces and fully or partially ornamented with twigs and leaves	4
3'. Bags with smooth surfaces and less or no ornamentations with short attachment..	7
4. Big-sized bags ornamented with long twigs and leaves	5
4'. Medium-sized bags ornamented with short twigs and leaves	6
5. Twigs arranged vertically on a silky bag in a circular pattern.....	<i>Eumeta crameri</i>
5'. A mix of twigs and leaves arranged vertically on a silky bag in an irregular pattern.....	<i>Eumeta variegata</i>
6. Long tubular bag fully ornamented with short twigs on a silky bag, length 25-30 mm.....	<i>Acanthopsyche cana</i>
6'. Cylindrical-shaped bags with both tapering ends and fully ornamented with tiny spikes of plant materials, length 8.5 – 12.5 mm.....	<i>Acanthopsyche alstoni</i>
7. Small-sized cylindrical bag without any ornamentations, tapering ends, length 10-12 mm	<i>Acanthoecia</i>(<i>Acanthoecia larminati</i>)
7'. Cone-shaped bags surface pasted with bits of leaves and bark, whitish cream colour bags, length 20-25 mm.....	<i>Manatha</i> <i>Manatha albipes</i>
8. Medium-sized (13-25 mm) bags; surface pasted with round-shaped leaf pieces and with an angle of attachment (20^0 - 50^0) to the substratum with a long thread	9
8'. Small-sized bags; surface pasted with leaf pieces, length 12-15 mm, attachment to the substratum with a long thread.....	(<i>Pteroma</i>) <i>Pteroma plagiophleps</i>
9. Whitish bags lengths 13-16 mm and the angle of the attachment of the bag is between 20^0 – 32^0	<i>Metisa plana</i>
9'. Whitish bags lengths 15-25 mm and the angle of the attachment of the bag is between 40 - 48^0	<i>Metisa canifrons</i>

10. Bags are made up of different materials like twigs, leaves, paper, and plastic(Typhoniinae)	11
10'. Bags made up of parts of lichen, algae, and bark	12
11. Medium-sized bags, made by oval/round shaped leaf pieces stacked on each other both sides.....	<i>Degiella</i>
11'. Small-sized bags made up of short sticks arranged vertically on a silky bag in an irregular pattern.....	<i>Struthisca</i>
12. Pupal bags are mostly seen associated with rocks	13
12'. Pupal bags are mostly seen associated with tree trunks(Taleporiinae)	
(Double-walled bags, hang on a thread on the tree branches and underside of the leaves, length 13-15 mm.....	<i>Capulopsyche keralensis</i>
13. Double-walled, Tubular bags wrapped with a sheath made up of different materials, length 8-11 mm.....	<i>Eumasia thomasi</i>
13'. Witches' hat' appearance, a disc-like anterior, and, a tubular posterior part, length 8-9 mm.....	<i>Eumasia venefica</i>

Table 9: Summary of the Bag architecture studies of bagworms in the study area

Subfamily	Species name	Shape	Colour	Length ♂/♀	Width AMP ♂/♀	Ornamentation & Materials	Habitat	Type of attachment and Substratum to the attachment	
Oiketicinae	<i>Eumeta crameri</i>	Cylindrical	Dark brown or black	45/50 mm	10,11,8 mm	Sticks arranged in a circular pattern	Plants	Small thread attachment	Plants/ branches of trees, the underside of leaves, walls, and bark.
	<i>Eumeta variegata</i>	Spindle with tapering ends	Greyish	38/45 mm	7,10,6/ 8,13,9 mm	silken threads, fragments of leaf, twigs, and bark	Plants	Small thread attachment	Plants/ Branches of trees
	<i>Manatha albipes</i>	Conical	whitish cream	20/25 mm	6,5,3/ 6.5,6,4 mm	silken threads, fragments of leaf, bark	Plants	Direct attachment	Plants/ branches of trees, the underside of leaves, and hard surfaces.

Subfamily	Species name	Shape	Colour	Length ♂/♀	Width AMP ♂/♀	Ornamentation & Materials	Habitat	Type of attachment and Substratum to the attachment	
	<i>Clania holmesii</i> cf	Spiral with a tapering distal end	brownish grey and black	16/19 mm	5,3,5,1.5/ 5,4,2 mm	Spirally arranged sticks, bits of leaves	Plants	Direct attachment	Plants/ Twigs, branches of plants
	<i>Acanthoea</i>	Cylindrical with both tapering ends	brownish grey and orange-brown	10 / 12 mm	1,2,1/ 1.5/2.5/1 mm	plants debris, silk, and dust. Spots and bands on the surface	Plants	Direct attachment to the substratum	Plants/ Walls, leaf surface
	<i>Acanthopsyche</i>	Long cylindrical	Whitish grey	25/30 mm	4,5,3/ 5,4,3.5mm	Silk, sticks, leaf fragments	Plants	Direct attachment	Plants/ Bark, wall
	<i>Acanthopsyche</i>	Cylindrical with anterior tapering	Blackish brown	8.5-9.5/ 11–12.5 mm	2.1 mm/ 2.8 mm	plant parts, bark tissues, silk	Plants	Direct attachment	Plants/ Wall, concrete slab, under the surface of leaves
	<i>Acanthopsyche</i> sp.	Long cylindrical	Whitish grey	30/ 35 mm	4.5,4,3/ 6,5.5,4 mm	Silk, sticks, leaf fragments	Plants	Direct attachment	Plants/ Bark, wall

Subfamily	Species name	Shape	Colour	Length ♂/♀	Width AMP ♂/♀	Ornamentation & Materials	Habitat	Type of attachment and Substratum to the attachment	
	Unidentified sp.1	Long conical	Whitish	40/ 55 mm	7, 6.5,5/ 9,8.5,6 mm	Silk, leaf fragments	Plants	Direct	Tree branches, twigs, the underside of leaves
	Unidentified sp.2	Long conical	Reddish brown	12 mm	4/2 mm	Silk, round leaf fragments arranged around the bag	Plants	direct	twigs, underside of leaves
	Unidentified sp.3	Long Tubular	Black	15 mm	3.5/1.5 mm	Silk, fragments of bark	Plants	Direct	Bark
	Unidentified sp.4	Long conical	Greyish brown	15-20 mm	-	Silk, leaf, and bark tissues	Plants	direct	Twigs, leaves
	Unidentified sp.5	Conical	Greyish	9.6 mm	1.7/3.5/2 mm	Silk, short sticks, thorns, leaves, flower parts, plastic, snail shell, feathers of birds, soil, small stones	Plants	direct	wall
	Unidentified sp.6	Conical	Blackish	13.7 mm	4/1.8 mm	Silk, leaf fragments	Plants	Direct	Leaves

Subfamily	Species name	Shape	Colour	Length ♂/♀	Width AMP ♂/♀	Ornamentation & Materials	Habitat	Type of attachment and Substratum to the attachment	
	Unidentified sp.7	Long conical	Grayish	17 mm	2.7,2,1.5 mm	Silk, leaf, and bark	Plants	Small thread	Wall, leaf, and twigs
Metisinae	<i>Metisa plana</i>	Cylindrical with both tapering ends	whitish cream	13/16 mm	2,2.5,1.5/3,4,2.5 mm	Silk, fragments of grass, leaf and sticks	Plants	Attached with thread	Plants/ The underside of Wall, leaves
	<i>Metisa canifrons</i>	Cylindrical with both tapering ends	Whitish	15/25 mm	3.5,3,2/4,3.5,3 mm	Silk, leaf fragments	Plants	Attached with thread	Plants/ The underside of Wall, leaves
	<i>Pteroma plagiohle</i>	Cylindrical with both tapering ends	Greyish brown	12/ 15 mm	1,2.5,1.5/1.5,3, 2 mm	Silk, leaf fragments, bark	Plants	Thread	Tree branches, twigs, the underside of leaves
Typhoniinae	<i>Degiella</i> sp.	Flat	Grayish white	18/ 25 mm	9,12,5/9,11,5 mm	Silk leaf pieces, plastic, paper	Terrestrial Lower plants	Direct	Wall
	<i>Struthisca</i> cf	Cylindrical	Greyish white	12/15 mm	1.5,2,2,5/2,3.5,2 mm	Silk, sticks, and grass arranged vertically	Terrestrial Lower plants	direct	Wall

Subfamily	Species name	Shape	Colour	Length ♂/♀	Width AMP ♂/♀	Ornamentation & Materials	Habitat	Type of attachment and Substratum to the attachment	
	Unidentified sp. 8	Long triangular	Brownish grey -	15-20 mm	3mm	Silk, algae, mosses	Lower plants	direct	Wall
Eumasiinae	<i>Eumasia thomasi</i> c	Tubular double walled	Blackish, brownish grey	8/11 mm	3.5-5/ 4.5-6 mm	Silk, sand, soil particles, snail shell, algae, and other insect debris	Rock/ Algae, lichen	Small thread	Wall, rock
	<i>Eumasia venefica</i>	Witches hat shape	Whitish green	8/ 9 mm	5,2,1.5 mm	Silk, lichen	Rock/ Algae, lichen	direct	Rock
	<i>Eumasia</i> sp.	Spindle	Whitish green	13 mm	2,6,2.5 mm	Silk lichen	Rock/ Algae, lichen	direct	Rock
Taleporiinae	<i>Capulops yche</i>	Tubular double walled	Blackish brown	13/ 15 mm	2,5,1.5/ 2,7,2.5 mm	Silk, bark tissue	Plant bark/Algae, lichen	Small thread	Bark, twigs
Unknown	Unidentified sp. 9	Long tubular	Reddish brown, whitish green	17 mm	0.8/2/1mm	Silk, bark, mosses	Plant bark/Algae, lichen	direct	Bark

4.5. Discussion

The study documented twenty-six different types of bags of Psychidae from the study area. Each of the bags has its unique shape and other characteristics. Table 9 shows a summary of the characteristics of the species. A similarity in bags was seen in closely related species. It indicates the similar ancestral origin of the species among each subfamily. The unidentified species (no adults) were classified under each subfamily with the help of phylogenetic analysis of COI sequences of all species using MEGA 11 (Tamura *et al.*, 2021).

The species in the subfamily Oiketicinae has similar habitat and feeding habits. All are phytophagous insects mainly inhabiting plants for their feeding and survival; therefore they are considered potential pests. The species use plant materials such as leaves, twigs, sticks, thorns, bark and flower for building bags along with silk threads.

Species in genus *Acanthopsyche* show a similar appearance in bag architecture. Three species in this genus; *A. cana*, *A. alstoni* and one unidentified species had the basic structure of as follows.; long cylindrical with tapering ends. Unique types of ornamentations on bags were another characteristic. In *A. cana*, the bag was covered with small sticks which gives a spiky appearance. In the unidentified species the ornamentations with sticks were present on the anterior and posterior regions. In *A. alstoni*, small minute spikes are seen on close observation. In phylogeny analysis ‘unidentified species 5’ is grouped with the genus *Acanthopsyche* and has also dense ornamentations on bags with different materials like silk, short sticks, thorns, leaves, flower parts, plastic, snail shell, feathers of birds, soil, small stones, etc. All the species in this group are voracious plant feeders in their larval stages except *A. alstoni*. The species *A. alstoni* is the smallest known species in the genus *Acanthopsyche*.

Genus *Eumeta* had two species in the study area, *E. crameri*, and *Eumeta variegata*. Larval bags of both species are among the largest of all bags collected. The vertical arrangement of long sticks, bag renovation, and the pattern of arrangement of *E. crameri* was previously studied by Agrawal & Pati, (2003, 2002). The findings from this study follow the results of Agrawal & Pati. Although they are the same genus, the larval bag architecture of *E. crameri* and *E. variegata* are slightly different only sticks are used in *E. crameri* but sticks, leaves and even other larval bags are used in the bags of *E. variegata*.

In Metisinae a close similarity in bags shape was observed in Genus *Metisa*: both *Metisa plana* and *Metisa canifrons* show very similar architecture of pupal bags, their attachment (with long thread), and inclination between bag and substratum, with major difference being the sizes of bags. In both cases, the bags are cylindrical with both ends tapering. *Pteroma plagiophleps* also had the same architecture, shape (cylindrical with both ends tapering) of the bag and the presence of a long thread for the pupal bag attachment. *Pteroma* and *Metisa* were placed close in the phylogenetic tree and formed the same cluster.

The larval bags of unidentified species nine in the unknown subfamily have an architectural resemblance with the larval bags of *Antillopsyche sessilis* Anguila and Davis, 2016, a new genus and species from Cuba.

Even though the species confirmation of Psychidae is not possible with the description of larval bags only, the uniqueness in bag making, its structure and other characteristics of larval bags are the identity of the species and have much significance in the identification process. Taxonomic classification and identification of larval bags could help in the preliminary identification of the bagworms as the bags can easily be sighted by even laypersons.

4.6. Conclusion

The uniqueness in the making and shaping of the bag in the species of Psychidae is significant for identification from a taxonomic and economic standpoint. As phytophagous insects, they consume numerous plants and this behaviour results in crop loss and economic loss. Farmers and laymen are unable to distinguish this potential pest from the surroundings of their farmed area because of its unique life history. But farmers can easily sight bags. Studies on bag morphology can become an essential tool for comprehending these species. Bag characteristics can also be used to place bags of unknown species in higher systematic levels like subfamilies. The presence of many “bags” unassigned to species indicate that long terms intensive studies are necessary to document all the psychids in the region.

PLATE 22

Larval and pupal bags of Psychidae – Identified species



a. Acanthoecia larminati



b. Acanthopsyche alstoni,
male and female pupal bags



c. Acanthopsyche cana



d. Acanthopsyche sp.



e. Eumeta crameri



f. Eumeta variegata, male and female
pupal bags

PLATE 23

Larval and pupal bags of Psychidae – Identified species



a. *Manatha albipes* male and female pupal bags



b. *Clania holmesi* (incertae sedis), female pupal bag



c. *Metisa canifrons*



d. *Clania holmesi* (incertae sedis), male pupal bag



e. *Metisa plana*, female and male pupal bags



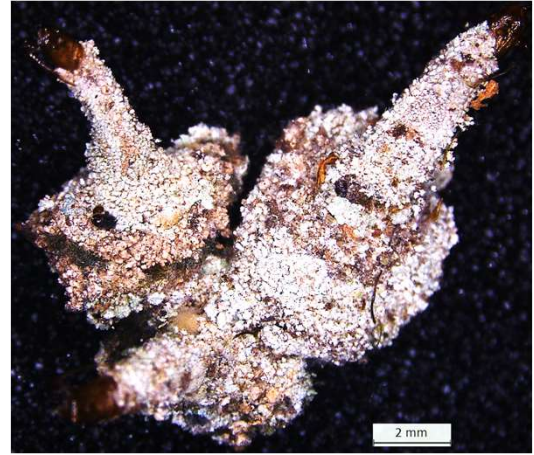
f. *Pteroma plagiophleps*

PLATE 24

Larval and pupal bags of Psychidae – Identified species



a. *Eumasia thomasii*



b. *Eumasia venifica* sp. nov.,
male and female pupal bags



c. *Struthisca* cf *farinosa*



d. *Degiella* sp.



e. *Capulopsycha keralensis* (male)



f. *Capulopsycha keralensis* (female)

PLATE 25

Larval and pupal bags of Psychidae – Unidentified species



a. *Unidentified species 1*,
male and female pupal bags



b. *Unidentified species 1*



c. *Unidentified species 2*



d. *Unidentified species 3*



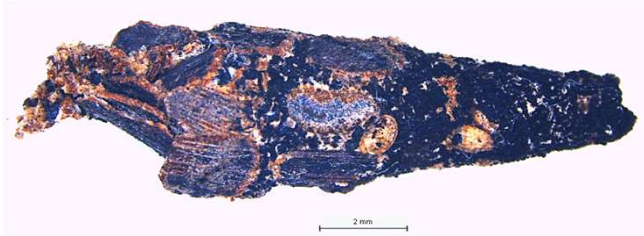
e. *Unidentified species 4*



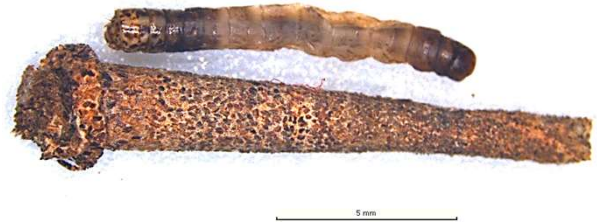
f. *Unidentified species 5*

PLATE 26

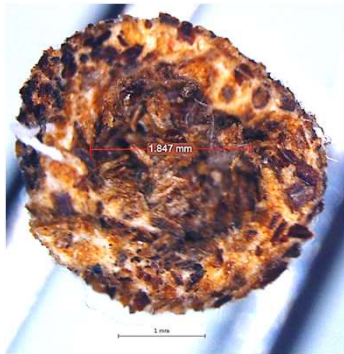
Larval and pupal bags of Psychidae – Unidentified species



a. *Unidentified species 6*



b. *Unidentified species 7 with larva*



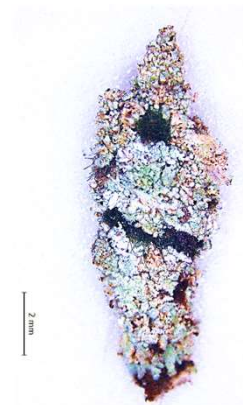
c. Anterior opening of the bag
Unidentified species 7



d. *Unidentified species 8*



e. *Unidentified species 9 with larva*



f. *Eumasia sp.*

CHAPTER 5

Host Plant Selection, Geographical Distribution and Threat Analysis of the species

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Host Plant Selection, Geographical Distribution and Threat Analysis of the species

5.1. Introduction:

Most of the species in Psychidae are plant feeders and have poly phytophagous nature causing severe defoliation in the plants so they are considered potential pests.

The environmental conditions act as a major factor for the bagworm's survival. Climatic conditions determine the adaptability of these organisms as pests. Knowing the biology of a pest is important for its control. Studies on the host plants infected, their distribution in a particular area and the habitat distribution of the host are very significant and should be documented before control measures start. The present study focuses on these aspects of the Psychidae in the study area.

5.2. Review of Literature

5.2.1 Ecology, host plants and pestilence reports of Bagworms

Studies on the ecology of bagworm species worldwide are mostly concentrated in the western hemisphere and these have immense importance in the field of agricultural entomology according to the relation between the environment and the survival of bagworms. Lynch *et al.* (2014) studied the overwintering mortality of bagworm eggs related to winter temperatures that are below the physiological limit of the bagworm species, *Thyridopteryx ephemeraeformis*, a major native pest of many trees in North America. The work demonstrated how species' sensitivity to climate extremes can lead to population tipping points that are not represented in demographic responses to climatic means, a distinction that is essential for accurate ecological forecasting.

The aerial dispersal and host plant selection of bagworm larvae of the species *Thyridopteryx ephemeraeformis* were studied in both artificial and natural habitats in Illinois (Moore & Hanks, 2004). Many experiments were conducted with the larval stage of *Thyridopteryx ephemeraeformis*, a major pest of arborvitae, juniper and maple in the USA. It was found that the dispersion of larvae mainly depended on the host plant which is most preferred by the larvae. The *Thyridopteryx ephemeraeformis* neonate larvae dispersed by ballooning on the wind. With the help of plant leaf fragments, larvae

make silken bags. They discovered that the larvae of this species, which is polyphagous, consumed more than 125 types of woody plants belonging to 45 families. According to the authors' proposed theory, the variation in larval dispersal and the time restriction on the ability to spread are what keep *Thyridopteryx ephemeraeformis* polyphagous. They deduced from laboratory research that starving or a lack of food can affect a larva's tendency to disperse from paper leaf models. Behaviour such as inflation, silking etc was affected by exposure to different types of foliage.

A study in the mid-western United States of America related the survival rate of bagworm eggs to extreme winter temperatures and the weight of egg clusters. and found that overwintering survival of bagworm eggs inside egg clusters is non-independent (Rhains *et al.*, 2013).

Studies on bagworm infestations are more common and have been reported from many places of the world. These infestations caused economic damage and nuisance to the surroundings. By taking proper control measures we can control or mitigate the infestations of pests. Knowing the biology and population dynamics is very important to control the attacks of insect pests such as bagworms and initiate appropriate control measures (natural, chemical, biological and IPR).

Comprehensive studies on *Eumeta carmeri* have been done in different places in Asia as they are a common species in this area. In Bangladesh, Ameen and Sultana (1977) studied the biology and lifecycle of *Eumeta carmeri* and reported they have four generations per year. A detailed study on the morphology and chaetotaxy of *Eumeta carmeri* were done in Karnataka, as per their report nine larval instars are possible for *Eumeta carmeri* in a life cycle (Thangavelu and Ravindranath, 1985). The studies on the distribution using QGIS mapping and hostplant preferences of the bagworm *Eumeta carmeri* was done in Kerala, the study listed 24 species of plants from 17 families from the study area infected by this species (Usha *et al.*, 2021).

Recent study reports of bagworm infestations from India are few especially from Kerala. Poorani *et al.* (2021) reported the attack of *Manatha albipes*, on coconut, banana, and areca nut plantations in South India, with emphasis on plantations in Tamilnadu. They have done a comprehensive study of the morphology and biology of the pest and presented it as an emerging pest of coconut, banana, and areca nut plantations. A threat assessment study of *Manatha albipes* in Kerala listed 19 different

plant species belonging to 14 families as the hostplants of this species and generated a distribution map of the bagworm with the prediction of its possible future attack in the coconut, banana, and arecanut plantations in Kerala (Usha *et al.*, 2022b).

The oldest records of bagworm infestations reveal the chance of the emergence of bagworm as a major pest in Kerala (Mathew and Nair, 1986). *Pteroma plagiophleps*, was most widespread all over Kerala (Mathew, 1985; Mathew and Nair, 1986). Outbreaks of this species were listed mainly from three different host plants such as pomegranate, *Albizia falcataria* (Nair *et al.*, 1981) and *Delonix regia* (Mathew and Nair, 1983). The presence of this species was also noted on another seven host plant species in Kerala. Four species, *Pteroma plagiophleps*, *Metisa plana*, *Manatha albipes* and *Brachycyttarus subteralbatus* were listed as main pests of tree crops of Kerala (Mathew and Nair, 1986).

According to the 1988 KFRI research report, *Pteroma plagiophleps* Hampson is a significant pest of *A. falcataria* in Kerala (Nair and Mathew, 1988). Except for the studies mentioned earlier no other recent official reports of bagworm attacks were available from Kerala. The mangroves around the Goa coast also have the presence of *Pteroma plagiophleps* Hamps (Santhakumaran *et al.*, 1995). *Rhizophora mucronata* is an important mangrove species along the west coast of India. Three species of bagworms, including *Brachycyttarus* sp., *Pteroma plagiophleps* and *Metisa* sp., were found in nursery plantations where they caused severe damage to young *Rhizophora mucronata* saplings by feeding on their tender leaves. Compared to the other two species, *Brachycyttarus* sp. was more prevalent and responsible for more than 60% of infestations over the total plant population (Remadevi & Raji, 2005).

The species *Pteroma plagiophleps* was reported from mangroves in Chettuvai, severely infesting *Rhizophora apiculata*, and *R. mucronata* (Therattil, 2013). Another report from Andhra Pradesh reports two species of bagworms, namely *Pteroma plagiophleps* Hamps and *Clania* sp. The infestation was seen as a central concentrated patch in the plantation (Emmanuel *et al.*, 2010). They estimated that there were 150–200 bagworms per leaf and most of the bagworms, after finishing their life cycle, proceeded towards the crown. The bagworms gathered on fruit bunches and leaf stacks. The attack severely reduced the amount of green foliage, which decreased yield. Severe infestations by a bagworm species *Eumeta crameri* Westwood were reported in a Ph.D. thesis from

Chhattisgarh, the study examined the attacks in different sites located in five districts of Chhattisgarh, namely Raipur, Durg, Rajnandgaon, Bilaspur and Bastar. About 14,177 numbers of trees belonging to 20 families and 36 species were infected by these bagworms in these areas (Agrawal and Pati, 2002). The species *Manatha albipes* is regarded as a pest of many plants in India, attacks on oil palm, areca nut and coconut plantations by these bagworms were reported in India and Sri Lanka (Dhileepan, 1991 a,b; Kalidas & Saravanan, 2013, Josephraj Kumar *et al.*, 2012; Kurian *et al.*, 1979; Nair & Daniel, 1982). Severe infestation out brakes were reported by this species in arecanut plantations from Shivamogga and Davanagere districts in Karnataka (Kalleshwaraswamy *et al.*, 2018). *Manatha albipes* were misidentified as *Psyche assamica* (Dierl, 1972) and *Kophene cuprea* Moore in India (Poorani *et al.*, 2021).

Oil palm plantations in Malaysia suffered from severe damage to three species *Pteroma pendula*, *Metisa plana* and *Mahasena corbetti* (Wood, 1971; Sankaran, 1970; Kamarudin *et al.*, 1994; Kamarudin and Basri, 2007). *Metisa plana* are the most widely distributed species followed by *P. pendula* in the oil palm plantations in Peninsular Malaysia (Kamarudin and Basri, 2007). In Bangladesh, *Pteroma plagiophleps* was observed on *Delonix regia* and its biology was investigated in the lab and outdoors between 1976 and 1986 (Howlader, 1992). Twelve host plants were noted in this study (*D. regia*, *Lagerstroemia indica*, *Albizia procera*, *Peltophorum inerme*, *Swietenia mahagoni*, *Spondias mangifera* [S. *pinnata*], and *Ixora coccinea*) (Howlader, 1992).

Another research from Peninsular Malaysia between 1986 and 2000 stated that *Pteroma pendula* and *Metisa plana* were significant oil palm pests based on the study at 69 oil palm estates and information on bagworm infestation was gathered from the estate's historical census data (Tuck *et al.*, 2011). Almost all ages of oil palms were susceptible to bagworm attack (Basri *et al.*, 1988). In Malaysia, *Acacia mangium* served as an alternative host for the *Pteroma pendula* pest population to build up its numbers and it also serves as a source of infestation to crops in the surrounding area (Cheong Loong *et al.*, 2010). The bagworm *Thyridopteryx ephemeraeformis* Haworth severely infected the ornamental plants in the south-eastern United States and they are considered as major pests (Jones and Parks 1928, Kaufmann 1968, Sheppard 1975, Leonhardt *et al.*, 1983, Rhainds and Sadof, 2008) and attacks were also seen in North America (Lynch *et al.*, 2014). *Thyridopteryx ephemeraeformis* is polyphagous and has a wide range of

host plant species about 125 species in 45 families (Davis, 1964; Moore and Hanks, 2004).

Phenology of bagworms is considered important for their control, i.e., to enhance synchrony between the timing of control measure and actively feeding larvae (Rhainds and Sadof, 2008). The intensity of larval damage to plants increases over time, so insecticide treatment becomes more effective in late instars (Kaufmann, 1968). Understanding the timing of the emergence of adult insects is more important when using pheromone traps for controlling bagworms through mating disruption (Klun *et al.*, 1986).

5.2.2. Chemical and Biological control of bagworms

Numerous research report publications emphasize mainly the control of bagworms; in these reports, chemical control is the most popular and widely used method.

Synthetic insecticides such as Trichlorfon, lambda-cyhalothrin, and cypermethrin EC are fast-acting and very effective against *Metisa plana* bagworms which infect oil palm plantations (Salim and Hamid, 2012). Effectiveness of insecticides like Chlorantraniliprole against *M. plana* had low to moderate ovicidal effects but was highly toxic to the neonates emerging from the eggs (Kok *et al.*, 2012). Another study related to the control of the same species *Metisa plana*, with two types of systemic insecticides, methamidophos and monocrotophos which were found to be very effective as the trunk injection of these insecticides completely eradicated the bagworm populations from the oil palm plantation (Salim *et al.*, 2015). In North Sumatra *Metisa plana* was controlled by carbosulfan treatments and it got positive results against these pests. Fogging insecticide technique was potentially effective as a spraying technique for higher canopy trees (Sudarsono *et al.*, 2011).

There are numerous studies on post-treatment behaviours of insects such as feeding activity, growth and larval mortality at various intervals in favour of the short-term death of larvae caused by various pesticides (Jacklin and Smith 1964, Bishop *et al.*, 1973, Neal 1981, Gill and Raupp 1994, Gill *et al.*, 2002). The effectiveness of various insecticide classes against bagworms *Thyridopteryx ephemeraeformis* on Arborvitae plants found that systemic insecticides like dinotefuran and chlothianidin applied to the soil increased larval mortality while decreasing larval growth and feeding rate. Both

chlorantranilipole and indoxacarb were also efficient in keeping bagworms under control. Systemic insecticides were especially effective in upper canopy control. (Rhains & Sadof, 2008).

Biological control of pests is done by using their natural enemies or parasitoids without any side effects on other organisms. In the case of bagworms, biological control was successfully employed in many places. Pheromone mass trapping was effectively used against *Metisa plana* in mature oil palms in Perak, Malaysia. Mass trapping reduces the chances of bagworm mating and oviposition, which leads to lower populations and therefore, lowers the attack (Kamarudin, *et al.*, 2010). A first-time report of the avian predation of bagworm moth *Thyridopteryx ephemeraeformis* by *Passer domesticus* (L.) was reported from the Eastern United States (Moore & Hanks, 2000). Aerial spraying with *Bacillus thuringiensis* (Bt) product in Southern Perak showed a 50% reduction of the *Pteroma pendula* population by 30 days after treatment (Mazmira *et al.*, 2011). Integrated pest management was also used for the control of bagworms (Ali *et al.*, 2005). Laboratory studies on several fitness parameters of parasitoids; developmental time, and pupal weights, longevity, fecundity, and sex ratio of progeny, etc was also conducted. Thirty-eight percentage of parasitism by hymenopteran parasitoids was recorded in the bagworm *Pteroma plagiophleps* from Kerala, India. A total of 18 species of parasitoids were listed from bagworm pupae collected from the forest trees *Paraserianthes falcataria*, *Delonix regia* and *Terminalia catappa*. Most of them belonged to Ichneumonidae or Chalcididae (Mathew, 1989)

An assessment study of the diversity of parasitoids carried out in the oil palm area of Perak, Malaysia recorded 59 parasitoids, belonging to two orders and seven families and 67 insects belonging to two orders and seven families and 68 insects belonging to two orders and six families were collected from three different areas by using trap method. Species abundance, diversity, richness, evenness and similarities of these parasitoids were also calculated. Diversity of parasitoids of the bagworms, *Metisa plana* and *Mahasena corbetti* (Wood and Kamarudin, 2019) revealed the presence of nine species of parasitoids common to both of the bagworms. Seven parasitoids from *Metisa plana* and three from *Mahasena corbetti* were reported.

In Kerala, seven parasitoid species from five different Hymenopteran families were reported in *Manatha albipes*. These parasitoids were *Brachymeria* sp. (Chalcididae),

Eurytoma sp. (Eurytomidae), *Pediobius* sp. (Eulophidae), *Elasmus* sp. (Eulophidae), *Paraphylax* sp. (Ichneumonidae), and two unidentified species from families Eurytomid (Usha *et al.*, 2022b) done as part of this research. As natural enemies of *Manatha albipes* from Tamilnadu, Poorani *et al.*, (2021) described one Hymenoptera, *Brachymeria* sp. (Chalcididae), an unidentified tachinid (Diptera: Tachinidae) and the pentatomid bug, *Eocanthecona furcellata*. In 2003, Noyes discovered two hymenopteran species from Sri Lanka, *Elasmus ceylonicus* Ferriere and *E. hutsoni* Ferriere (Hymenoptera: Eulophidae), attacking the bagworm *Manatha albipes*.

Many other factors control the growth of the population of bagworms. Parasitoids, fungi, bacteria, entomopathogenic nematodes, insectivorous birds and rodents are involved in this control process (Hardenberg, 1919). The bagworm fungus *Isaria farinosa*, (Pole, 1912), a naturally occurring entomopathogenic fungus was found to be distributed through many wattle plantations in South Africa. The spores of this fungus present on the plant leaves enter inside the bagworms' stomach via feeding. The caterpillar dies in about five days after infection and the body becomes mummified (Hardenberg, 1919). Compared to biocontrol applications of chemical pesticides such as synthetic pyrethroid cyfluthrin, provided the best and most consistent control under all conditions (Gill & Raupp, 1994). The efficiency of Rhamnolipid, a biosurfactant generated by *Pseudomonas aeruginosa* USM-AR2 in causing bagworm mortality was investigated in Malaysia. Its efficacy as a biopesticide for controlling the species *Metisa plana* in oil palm fields got positive results and found to be more effective than cypermethrin (Zaludin *et al.*, 2021).

5.3. Methodology

5.3.1 Checklist of the Hostplants

5.3.1.1 Data collection

a) Field survey and checklist preparation: The studies were conducted in randomly selected habitats in Kerala mainly human habitations or human-altered areas, thick vegetation and individual plants or trees. The plants infected by the bagworms were noted from the area and photos of the plants or trees were taken. The plant parts like leaves, twigs and flowers were collected for identification. The identification of plants was done with the help of experts in plant taxonomy. The identified plants of each

species were sorted according to the family and tabulated. The checklist of the identified bagworm species hostplants in the study area was prepared.

5.3.1.2 Data analysis: The host plants of only identified bagworm species was considered for this section of the study. The consolidation of data and graphical representations was done in Microsoft excel. The utilization of host plants by the bagworms based on the bag size (instars), bag position, number of bags, plant type and feeding were visualized using Principal Component Analysis (PCA) by PCA biplots and dendrogram clustering for various data using the software PAST 4.10. The components used for various visualizations are the following:

a) Bag positioning: Host plant data collected during fieldwork was classified based on different objectives like bag positioning on a plant/ tree, bag attachment, and type of the plant are follows (Usha *et al*, 2021),

- i. Bag position was noted as the top(T), middle(M), and Bottom(B), by roughly dividing the plant into three equal parts.
- ii. Bag attachment was classified as “on stem” (S), on Trunk(T) and “on leaf” (L).
- iii. The plants were also classified based on the type, such as tree, shrub, and herb.

b) Plant utilization and damage: Damage to the leaves near the bags, and all over the hostplant, due to feeding by the larvae was calculated as follows:

Damaged leaves were randomly selected for measurement. Based on the damage observed in the plant parts, i.e., mainly in the leaf area, gave different scores. For no damage observed, score zero; less than $\frac{1}{4}$ of the leaf area damaged, score 1; $\frac{1}{4}$ to $\frac{1}{2}$ of the leaf area damaged, score 2; and $\frac{1}{2}$ to $\frac{3}{4}$ of the leaf area damaged, score 3; more than $\frac{3}{4}$ of the leaf area damaged, score 4 (Usha *et al*, 2021).

5.3.2. Distribution Mapping: Data of distribution was tabulated for individual species with geo-coordinates of the places. Maps were created based on the occurrence of species. The geocoordinates were plotted on Survey of India (SOI) toposheets using QGIS (open-source GIS software) to generate maps. Rainfall range, temperature range and altitude maps were obtained from the resource atlas published by CESS and overlayed on the location map. The results were compared with those obtained from ground truthing. Total distribution area, N- S and E -W extent was calculated for each species.

5.3.3. Threat analysis of selected species: Threat assessment studies of selected bagworms species were done. The species were selected according to the frequency and severity of the attacks on economically important plants and trees in Kerala. Five bagworm species found as major threats to the plants in the study area were *Eumeta crameri*, *Manatha albipes*, *Acanthopsyche cana*, *Pteroma plagiophleps* and *Metisa canifrons*. A distribution map of all the species including above five species was created in QGIS by plotting the geo-coordinates of the species occurrences in the study area. The digital maps of areas in Kerala with similar land use and mixed plantations (Source: CESS Land use Maps) of the hostplants of these species were used to demarcate agricultural land which could be affected by these species. The potential area that could be affected by bagworms, presently under major crops was calculated.

5.3.4. Collection and identification of natural enemies of bagworms (parasitoids)

The parasitoids were collected from the rearing bottles of bagworm at the time of their emergence. The collected specimens were preserved in small plastic vials (2 ml) both in dry and wet conditions (in absolute alcohol) for the identification. The collected specimens are then identified up to family, genus and species level by referring to experts.

5.4. Results

5.4.1. Checklist of the Host plants

The study listed seventy-three hostplant species belonging to thirty-eight families infected by nine bagworm species from the study area. The checklist of the hostplants is given in the Table 10. (Plates 27, 28)

Table 10: Checklist of the hostplants infected by the bagworms in the study area

No	Species	<i>E. crameri</i>	<i>M. albipes</i>	<i>P. plagiophleps</i>	<i>M. canifrons</i>	<i>M. plana</i>	<i>Clania holmesi</i> <i>cf</i>	<i>A. cana</i>	<i>A. alstoni</i>
1.	<i>Phyllanthus emblica</i>	****	****	**	**	0	**	0	0
2.	<i>Casuarina equisetifolia</i>	***	**	0	0	*	*	0	0
3.	<i>Terminalia catappa</i>	***	****	****	***	0	0	0	0
4.	<i>Tamarindus indica</i>	**	*	*	0	0	0	0	0
5.	<i>Psidium guajava</i>	**	*	*	0	0	0	0	0
6.	<i>Mangifera indica</i>	**	0	0	*	*	0	0	0
7.	<i>Mikania micrantha</i>	**	0	0	0	0	0	*	0
8.	<i>Lawsonia inermis</i>	**	0	0	0	0	*	0	0
9.	<i>Hyptis suaveolens</i>	**	0	0	0	0	0	0	0
10.	<i>Lagerstroemia speciosa</i>	**	*	*	*	*	*	*	*
11.	<i>Sida acuta</i>	**	0	0	0	0	0	0	0
12.	<i>Tectona grandis</i>	**	*	0	0	0	0	0	0
13.	<i>Urena sinuata</i>	*	0	0	0	0	0	0	0
14.	<i>Phyllanthus myrtifolius</i>	*	0	0	0	0	0	***	0
15.	<i>Butea monosperma</i>	*	*	0	0	0	0	0	0
16.	<i>Caesalpinia coriaria</i>	*	0	0	*	0	0	0	0
17.	<i>Ipomoea marginata</i>	*	0	0	0	0	0	0	0
18.	<i>Chromolaena odorata</i>	*	0	0	0	0	0	0	0
19.	<i>Syzygium cumini</i>	*	*	0	0	0	0	0	0
20.	<i>Theobroma cacao</i>	*	0	*	0	0	0	0	0
21.	<i>Melaleuca leucadendra</i>	*	0	0	0	0	0	0	0
22.	<i>Trema orientalis</i>	*	0	0	0	0	0	*	0
23.	<i>Mimosa pudica</i>	*	0	0	0	0	0	0	0
24.	<i>Crotalaria pallida</i>	*	0	0	0	0	0	0	0

No	Species	<i>E. crameri</i>	<i>M. albipes</i>	<i>P. plagiophleps</i>	<i>M. canifrons</i>	<i>M. plana</i>	<i>Clania holmesi</i> <i>cf</i>	<i>A. cana</i>	<i>A. alstoni</i>
25.	<i>Phyllanthus reticulatus</i>	*	0	0	0	0	0	***	0
26.	<i>Cleome viscosa</i> L.	*	0	0	0	0	0	0	0
27.	<i>Acacia auriculiformis</i>	*	0	0	*	0	0	0	0
28.	<i>Dyopsis lutescens</i>	0	***	0	**	0	0	0	0
29.	<i>Pongamia pinnata</i>	0	****	0	*	0	0	0	0
30.	<i>Cassia fistula</i>	0	**	0	0	0	0	0	0
31.	<i>Syzygium samarangense</i>	0	**	0	0	0	0	0	0
32.	<i>Heliconia rostrata</i> ,	0	**	0	**	*	0	0	0
33.	<i>Terminalia cuneata</i>	0	*	0	*	0	*	0	0
34.	<i>Terminalia panniculata</i>	0	*	0	0	0	0	0	0
35.	<i>Cocos nucifera</i>	0	*	0	0	0	0	0	0
36.	<i>Elaeis guineensis</i>	0	*	0	0	0	0	0	0
37.	<i>Roystonea regia</i>	0	*	0	0	0	0	0	0
38.	<i>Avicennia officinalis</i>	0	*	0	0	0	0	0	0
39.	<i>Musa paradisiacal</i>	0	*	0	0	0	0	0	0
40.	<i>Billbergia pyramidalis</i>	0	*	0	0	0	0	0	0
41.	<i>Calliandra haematocephala</i>	0	*	0	0	0	0	0	0
42.	<i>Hibiscus rosa-sinensis</i> ,	0	*	0	0	0	0	0	0
43.	<i>Jasminum sambac</i> ,	0	*	0	0	0	0	0	0
44.	<i>Ixora coccinea</i>	0	*	*	0	0	0	*	0
45.	<i>Magnolia champaca</i>	0	*	0	*	0	0	0	0
46.	<i>Delonix regia</i>	0	0	***	0	0	0	0	0
47.	<i>Annona muricata</i>	0	0	*	0	0	0	0	0
48.	<i>Terminalia neotaliala</i>	0	0	*	0	0	0	0	0
49.	<i>Epipremnum aureum</i>	0	0	*	0	0	0	0	*

No	Species	<i>E. crameri</i>	<i>M. albipes</i>	<i>P. plagiochleps</i>	<i>M. canifrons</i>	<i>M. plana</i>	<i>Clania holmesi</i> <i>cf</i>	<i>A. cana</i>	<i>A. alstoni</i>
50.	<i>Chrysophyllum cainito</i>	0	0	0	*	0	0	0	0
51.	<i>Tecoma stans</i>	0	0	0	*	0	0	0	0
52.	<i>Piper nigrum</i>	0	0	0	*	0	0	*	0
53.	<i>Gmelina arborea</i>	0	0	0	*	0	0	0	0
54.	<i>Cyrtostachys renda</i>	0	0	0	*	*	0	0	0
55.	<i>Borassus flabellifer</i>	0	0	0	0	*	0	0	0
56.	<i>Allamanda cathartica</i>	0	0	0	0	0	*	0	0
57.	<i>Polyalthia longifolia</i>	0	0	0	0	0	*	0	0
58.	<i>Cardiospermum halicacabum</i>	0	0	0	0	0	*	0	0
59.	<i>Ficus benjamina</i>	0	0	0	0	0	*	0	*
60.	<i>Hydrangea macrophylla</i>	0	0	0	0	0	0	*	0
61.	<i>Garcinia gummi-gutta</i>	0	0	0	0	0	0	*	0
62.	<i>Coffea arabica</i>	0	0	0	0	0	0	0	**
63.	<i>Datura arborea</i>	0	0	0	0	0	0	0	**
64.	<i>Thuja occidentalis</i>	0	0	0	0	0	0	0	*
65.	<i>Madhuca neriifolia</i>	0	0	0	0	0	0	0	*
66.	<i>Dracaena trifasciata</i>	0	0	0	0	0	0	0	*
67.	<i>Tradescantia spathacea</i>	0	0	0	0	0	0	0	*
68.	<i>Dracaena reflexa</i>	0	0	0	0	0	0	0	*
69.	<i>Grevillea robusta</i>	0	0	0	0	0	0	0	*
70.	<i>Araucaria heterophylla</i>	0	0	0	0	0	0	0	*
71.	Unknown	*	0	0	0	0	0	0	0
72.	Unknown	0	0	0	0	0	0	*	0
73.	Unknown	0	*	0	0	0	0	0	0

5.4.1.1. Diversity in Host Plant Selection

Nine species of bagworms were observed as actively involved in plants for feeding and pupal bag attachment. Most of them cause damage to plants, and others do not cause any damage but depend on the plants for completing their life cycle in many other ways. The species showing phytophagy are the following

a) *Eumeta crameri* Westwood 1854

Twenty-three species of plants belonging to 12 known and one unknown family were seen to be infected by *E. crameri*. Out of 23 species, 14 were trees, two were herbs and seven were shrubs. *Phyllanthus emblica*, *Casuarina equisetifolia*, *Terminalia catappa*, *Tamarindus indica* were frequently found infested by *Eumeta crameri*, and Phyllanthaceae is the most affected plant family (Fig.34). The bags were mostly positioned in the middle of the host plant, irrespective of the species being a tree, herb, or shrub. The maximum number of bag attachments is seen at the internodes. Bags on the leaves were fewer in number than those attached to the stem. Though more bags were found in the middle third of the host plant in general, there is a significant increase in the bags attached to the upper third in trees, compared to shrubs and herbs. Less feeding has been observed in trees than in shrubs and herbs (Usha *et al.*, 2021).

b) *Pteroma plagiophleps* Hampson, 1892

Pteroma plagiophleps severely infects plants by feeding and defoliating leaves. Eleven species of plants belonging to the nine families were seen to be infected by these bagworms. Out of 11 species nine were trees and two were shrubs. *Terminalia catappa* was frequently seen infested by *Pteroma plagiophleps*, followed by *Delonix regia*. Combretaceae is the most affected plant family (Fig.32). All the other host plants suffered severe damage by this bagworm. At the time of feeding, they stick on the leaves of hostplants, and at rest, they move on the stem or twig and attach their bags there. The observation of the attack on *Phyllanthus emblica* plant from Vallachira (Plate 28a) was evident in the severity of the infestation of this species during the field visits. The larvae ate the entire leaves and tender shoots of plants and totally defoliated them. Few reports were available related to the attack of *Pteroma plagiophleps* in forest trees of Kerala and all mentioned *Delonix regia* as the main host plant of this species. *Delonix*

regia was observed as one of the host plants of *Pteroma plagiophleps* during the present study too.

c) *Manatha albipes* Moore, 1877

Manatha albipes is a polyphagous insect pest that severely infects plants. Twenty-eight species of plants belonging to 16 families were seen to be infected by these bagworms. Out of 28 species, 22 were trees, three were shrubs and three herbs. *Terminalia catappa* and *Phyllanthus emblica* were frequently found infested by *Manatha albipes*. Combretaceae is the most affected plant family followed by Fabaceae (Fig.33). These species represent twenty-two new records for *M. albipes* host plants in Kerala. In Tamil Nadu and Karnataka, *M. albipes* have recently become a significant pest of banana and arecanut trees (Poorani *et al.* 2021). However, considering the results of Poorani *et al.* (2021), a few farmers having banana and arecanut on their household farm were informally interviewed and they were able to identify the bags of *M. albipes* as seen on their plants.

The host plant's internode, lamina, and bark showed maximum bag attachment. During their final instar or pupal stage, the bagworm cases accumulated on the middle or bottom parts of the trees, especially in big groups on the bark region (Fig.33). In many instances, significant damage to the plants has been seen by the larva from earlier instars actively feeding the leaf lamina and creating holes in the leaves (Fig.33) (Plate 29).

Except for reports of infestations on a few commercially significant crops including oil palm and coconut (Dhileepan 1991; Josephraj Kumar *et al.*, 2012), banana, and arecanut (Poorani *et al.*, 2021) detailed research on the host plants of *M. albipes* was absent in India. Arecaceae is an economically important plant family in Kerala and eight species from this family were hostplants of *Manatha albipes* in this study. They were *Cocos nucifera*, *Dyopsis lutescens*, *Elaeis guineensis*, and *Roystonea regia*. *Manatha albipes* was seen first time from mangroves (*Avicennia officinalis*) from Kerala, India. The larvae feeding on the leaves of *Avicennia officinalis* was spotted in Chettuva mangroves.

The results provide evidence of the widespread occurrence of *M. albipes* from numerous host plants over the whole state of Kerala. According to Goodell (2009), these plants near farms and households might act as spillover sources and reservoirs for

insect populations, raising the prospect that they could become a serious threat to Kerala's agricultural industry.

d) *Metisa canifrons* Hampson, 1910

Metisa canifrons infested 15 species of plants belonging to 11 families. Out of 15 species, 13 were trees, one shrub and one herb. *Terminalia catappa* and *Phyllanthus emblica* were frequently found infested by *Metisa canifrons*. Combretaceae and Phyllanthaceae were the most affected plant family by this species (Fig.31). *Dyopsis lutescens* (Arecaceae) and *Piper nigrum* (Piperaceae) were economically important crops infested by *M.canifrons*. Young larvae eat the leaf lamina and make round-shaped perforations on the leaf surface. At the time of feeding, they stay on the surface of the leaves and move to the underside while resting.

Feeding by larvae was observed on other plants namely *Terminalia catappa*, *Phyllanthus emblica*, *Dyopsis lutescens*, *Cyrtostachys renda*, *Pongamia pinnata* and *Magnolia champaca*. Only pupal cases were found on the rest of the plants. The pupal bags of this species were attached to the underside of leaves and internodes of the stem of their hostplants and even attached to the edges of buildings, walls, etc.

e) *Acanthopsyche cana* and *Acanthopsyche sp.* Hampson, 1892

Acanthopsyche species prefer polyphagy and mostly depend on herbs and shrubs for feeding during their early instars. They damage these plants by vigorous feeding. Trees are found rarely infested by these genera but they preferred the bark of trees to attach at the time of pupation. Nine species of plants belonging to eight families were recorded as host plants of these bagworms. Out of nine species, three were trees, four shrubs and two herbs. *Phyllanthus reticulatus* and *Phyllanthus myrtifolius* were frequently found infested by *Acanthopsyche species*. Phyllanthaceae was the most affected plant family by this species (Fig. 29).

Larvae actively fed on the herbs and shrubs (*Phyllanthus reticulatus* Poir, *Phyllanthus myrtifolius*, *Mikania micrantha*, *Hydrangea macrophylla*, *Piper nigrum* and *Ixora coccinea*). Only pupal bags were collected from the bark of the trees (*Trema orientalis*, *Garcinia gummi-gutta*).

f) *Metisa plana* Walker, 1883

Metisa plana is a defoliator pest of several plants such as oil palm. Five species of plants were recorded as hostplants of this bagworm from Kerala. Four were trees and one was a shrub. Arecaceae is the dominant family in the list. The history of *Metisa plana* attacks was mostly on Arecaceae family worldwide. The pupal bags were found attached to the underside of the leaves of plants such as *Casuarina equisetifolia*, *Mangifera indica*, *Heliconia rostrata*, *Cyrtostachys renda* and *Borassus flabellifer*. Feeding damage was not seen on any of the plants listed, we could see many pupal cases attached on the surface and underside of walls, buildings, etc during pupation.

g) *Clania holmesi* incertae sedis Watt, 1898

The species are polyphagous and found on nine species of plants belonging to nine families of which six were trees, two were shrubs and one was a herb. *Phyllanthus emblica* and *Lawsonia inermis* were the frequently infested hostplants of *C. holmesi*. Phyllanthaceae were the most infested host plant family of this species, followed by Lythraceae. The larvae were seen actively feeding on the leaves of the plants such as *Lawsonia inermis*, *Cardiospermum halicacabum*, *Phyllanthus emblica*, *Allamanda cathartica*, *Polyalthia longifolia*, and *Casuarina equisetifolia*.

h) *Acanthopsyche alstoni* Watt & Mann, 1903

Twelve species belonging to eleven families of plants are recorded as host plants of this species (Table 10) of which seven were trees, four were shrubs and one was an herb. The larval cases were found moving actively on hard surfaces such as walls, concrete slabs, building surfaces and on live plants. The pupal cases were attached to different plant species. Significant damage to plants by this species were not observed. Maximum sightings of larval cases were from the surfaces of hard objects like walls, gates, etc in their larval stages. The pupae were attached mostly to the underside of leaves, twigs, and bark.

Other Species: *Eumeta variegata* was recorded from two places in the two districts of Kerala, Kannur, and Malappuram on two of hostplants (*Casuarina equisetifolia* (Casuarinaceae) and *Phyllanthus emblica* (Phyllanthaceae)). Only pupal bags of *Eumeta variegata* were collected from the trees. The attachment of pupal bags was seen on the nodes of the host plants.

There were no hostplants listed for the other species of bagworm namely *Acanthoecia larminati*, *Struthisca* cf *farinosa*., *Degiella* sp. nov, *Eumasia thomasii*, *Eumasia venefica* and *Capulopsyche keralensis*. *Acanthoecia larminati* is a small bagworm species mainly found attached to the surface of walls and buildings and found attached to the leaf of *Mangifera indica* from two study locations, but the evidence of feeding on *Mangifera indica* plant was not seen. It is hypothesized that these species feed on bark/algae/ moss by scraping the bark surfaces.

Struthisca cf *farinosa* and *Degiella* sp.nov. from the subfamily Typhoniinae are mainly collected from the surface, edges and underside of the walls and buildings. No specimens were collected from plants. The larval cases of *Struthisca* cf *farinosa* are made up of small twigs from the grass, and the observations of its many cases in and around the rocks near the grasslands lead to the assumption that they could feed on grass and/or other lower plants. Hostplants record for *Degiella* sp.nov. is not available. They are found attached to the surface and underside of walls; no feeding was observed on plants. But their bags are made up of bits of leaves and other materials.

The larval cases of *Eumasia thomasii* and *Eumasia venefica* were collected from underside of rocks. Active larvae were observed scrapping the surface of the rocks and it is assumed that the larvae fed on the algae and mosses on the rocks following previous reports (Saigusa and Sugimoto 2013; Roh and Byun 2016, Roh *et al.*, 2018). Bits of algal and mosses retrieved from the larval cases also indicated this.

Capulopsyche keralensis was found from coffee plantations from two different places in Kerala. The larvae of this species were found scraping on the bark of trees and were supposed to feed algae, mosses and other tissues on the bark.

5.4.1.2. Species richness of bagworms in major plants

Based on the nine bagworm species and their hostplants selections. Figure 25 represents the number of plant families and species infected by the bagworm species. *Eumeta crameri* and *Manatha albipes* has a greater number of hostplant species and families, 28 host plant species each and 14 and 16 plant families respectively. *Metisa canifrons* has 15 host plants species belonging to 11 families; *Pteroma plagiophleps* infested 11 species of 9 families, *Clania holmesi* cf infested 10 species from 8 families, *Acanthopsyche cana* and *Acanthopsyche* sp. infested 9 plant species from 7 families,

Acanthopsyche alstoni infested 12 species from 11 families. *Metisa plana* infested five plant species belonging to 4 families.

The dendrogram visualization of the host plant family (Fig. 26) and species preferences (Fig. 27) shows the similarity of preferences within each bagworm species. Based on the clusters formed on the basis of host plant selection it was concluded that the similarity of plant preferences is not because of the plants they have chosen to host but because of the plants they have as not-chosen as host plants. Some species infested few hostplants as in *Metisa plana*, *Clania holmesi* cf, *A.alstoni* and *M.canifrons*.

The species showed more distance on the dendrogram when more number and variety of hostplants were involved, as in *Eumeta crameri* and *Manatha albipes* (Fig 26). *Manatha albipes* and *Pteroma plagiophleps* were grouped together based on similar hostplant preferences (Fig.27).

Species richness (Table:11) of bagworm pests was higher in *Phyllanthus emblica* and *Lagerstroemia speciosa*. Five species of bagworms are observed in these plants. Four species were observed in *Casuarina equisetifolia* and *Terminalia catappa*. Three species of bagworms are found on *Tamarindus indica*, *Psidium guajava*, *Mangifera indica*, *Heliconia rostrata*, *Terminalia cuneata* and *Ixora coccinea*.

The highest **Shannon diversity** (Table:12) values in hostplants based on the infestation of bagworm species was in *Lagerstroemia speciosa* (1.744), followed by *Terminalia cuneata* and *Ixora coccinea* (1.432). *Phyllanthus emblica* (1.34) and *Casuarina equisetifolia* (1.316). These values reflected the number of individuals in each species of bagworms on a particular host plant. *Lagerstroemia speciosa* had more numbers of species and individuals infesting it.

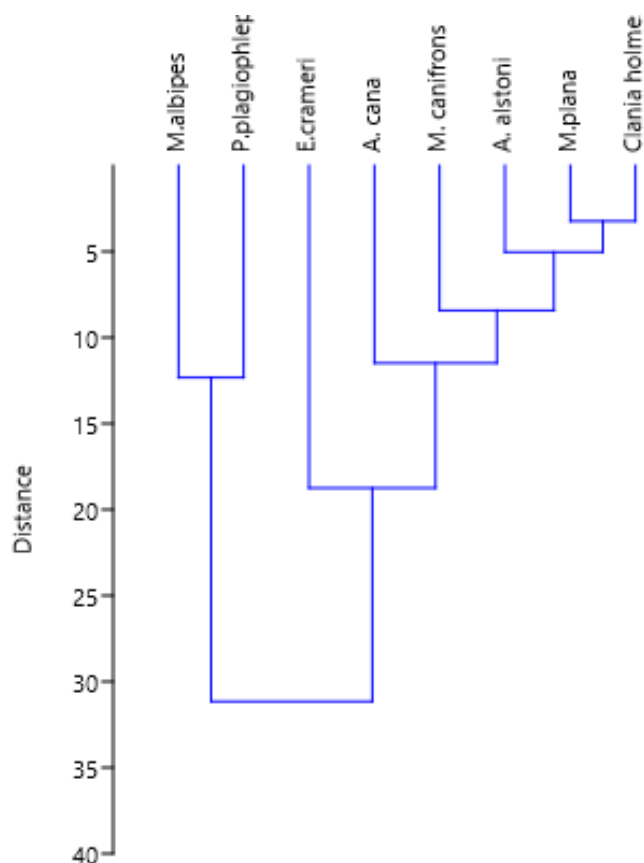


Figure 27: Grouping of bagworm species based on their host plant species preference

(Wards' method – algorithm; Euclidean Distance-Similarity index) PAST Ver 4.10-
Cluster analysis

Table 11: Species richness of Bagworms in major host plants

No	Hostplant species	Species richness
1	<i>Phyllanthus emblica</i>	5
2	<i>Lagerstroemia speciosa</i>	5
3	<i>Casuarina equisetifolia</i>	4
4	<i>Terminalia catappa</i>	4
5	<i>Tamarindus indica</i>	3
6	<i>Psidium guajava</i>	3
7	<i>Mangifera indica</i>	3
8	<i>Heliconia rostrata,</i>	3
9	<i>Terminalia cuneata</i>	3
10	<i>Ixora coccinea</i>	3

Table 12: Diversity in host plants for selected bagworm species- Shannon Diversity index

No	Plant species	Shannon Diversity index
1	<i>Lagerstroemia speciosa</i>	1.744
2	<i>Terminalia cuneata</i>	1.432
3	<i>Ixora coccinea</i>	1.432
4	<i>Phyllanthus emblica</i>	1.34
5	<i>Casuarina equisetifolia</i>	1.316
6	<i>Terminalia catappa</i>	1.224
7	<i>Mangifera indica</i>	1.178
8	<i>Heliconia rostrata</i> ,	1.178
9	<i>Psidium guajava</i>	1.15
10	<i>Tamarindus indica</i>	1.099

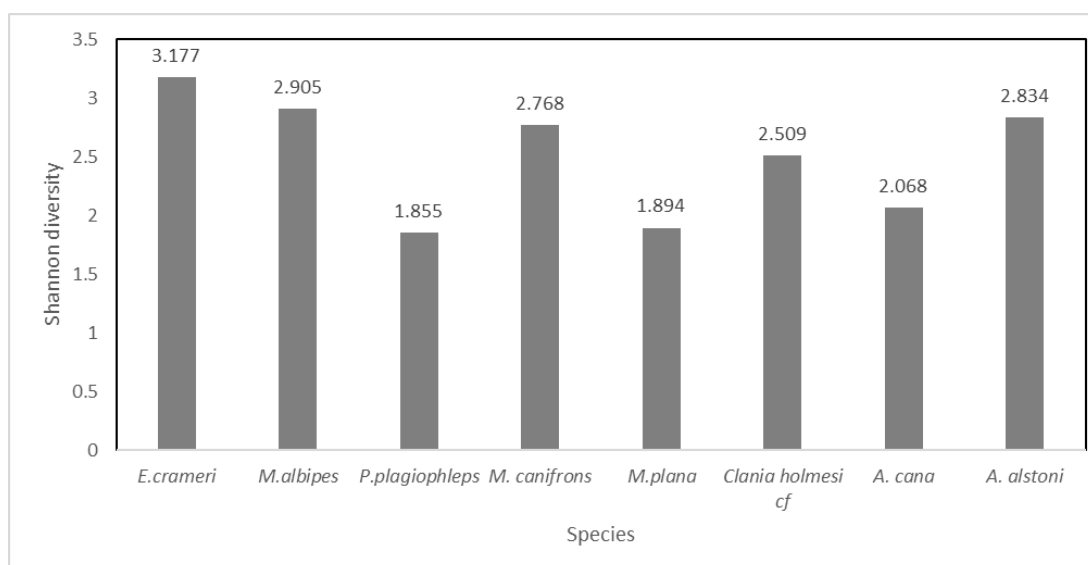


Figure 28: Graphical representation of Diversity in host plants for selected bagworm species Shannon Diversity index

E. crameri and *M.albipes* infested the maximum number of species and stems which was reflected in the high Shannon index calculated from the species and individual stems of hostplants/bagworm species (Fig. 28

5.4.1.3. Bag positioning and damage assessment in Psychidae species

The bag positioning of the larvae on hostplants and damage is visualized by creating PCA maps. The PCA analysis of *Acanthopsyche cana* and *Acanthopsyche sps* of the bag attachments are mostly seen on the leaf and stem regions of the hostplants. Larvae voraciously feed leaves and makes holes, attaching their bags underside of the leaves during between the feeding or rest. The last instar bags feed less and prefer bottom side of the plant or tress for attaching their pupal bags; most individual pupal bags were found on the walls of buildings and other hard surfaces (Fig. 29)

The species *Clania holmesii* was found on all the types of plants such as trees, herbs and shrubs and they mostly observed on trees. The bags were found singly or in groups of three or four on each hostplant, larvae feed on leaves and bags attached on the stem or branches of trees at the time of pupation. No significant damage to trees by this species observed. (Fig 30).

Metisa canifrons are voracious feeders on plants and inhabited as larval groups on host plants. Early instarlarvae feed on leaves and cause damage, both on trees and herbs..Pupal bags were found singly in plants with no damage observed. (Fig 31).

Pteroma plagiophleps, *Manatha albipes* and *Eumeta crameri* caused most damage and infested more plant species and stems.

Pteroma plagiophleps causes damage to trees mostly, severe defoliation in plants was noted as early instar larvae feed on leaves and makes damage and inhabit as large groups in a plant. Larval bags were attached to the surface of leaves at rest and the pupal bags were attached to the underside of the leaves and tree branches with a long thread. (Fig 32).

Manatha albipes are also a defoliator pest of plants and they infest plants and shrubs mostly. The larval stage of this species causes severe damage to trees by its feeding behaviour. Herbs were least infected compared to other plant types. Huge numbers of larval bags were observed in many trees during the study period, and the pupal bags were attached as large groups on the trunk region of the trees (Fig 33).

Eumeta crameri fed on all the types of plants and the early instar larvae prefer herbs and shrubs. Last instar preferred trees for feeding and pupation. The mature larvae

migrated to trees before pupation as evidenced by the relative size of the bags that were taken from the trees. (Fig 34).

The peculiar characteristics of bag positioning, feeding and damage were reflected in the PCA maps.

No damage was caused by *Metisa plana* and *Acanthopsyche alstoni* by feeding hostplants. Only pupal bags of these species were seen on the plants. Attachments of pupal bags are seen on the leaf and stem of the hostplants of both species.

The documentation of the activities of larvae on their host plants like bag positioning, feeding, and damage, will help to analyse the distribution patterns of these potential pests on their host plants and assist in formulating appropriate control methods.

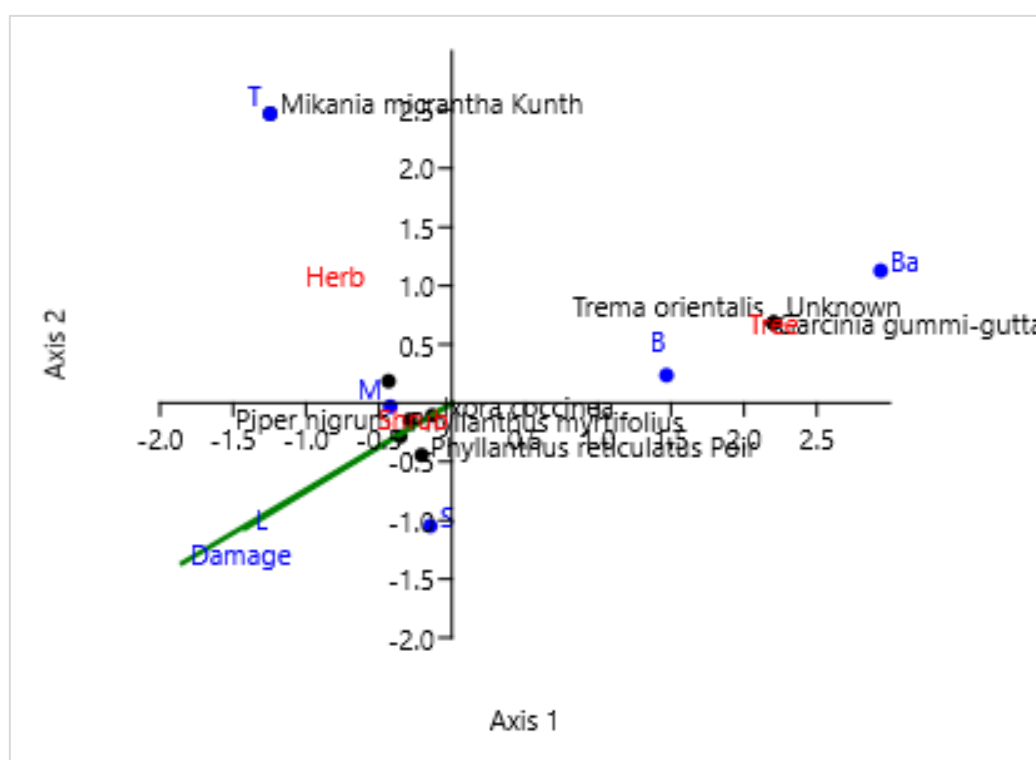


Figure 29: PCA analysis of bag positioning and damage by *Acanthopsyche cana* and *Acanthopsyche sps*

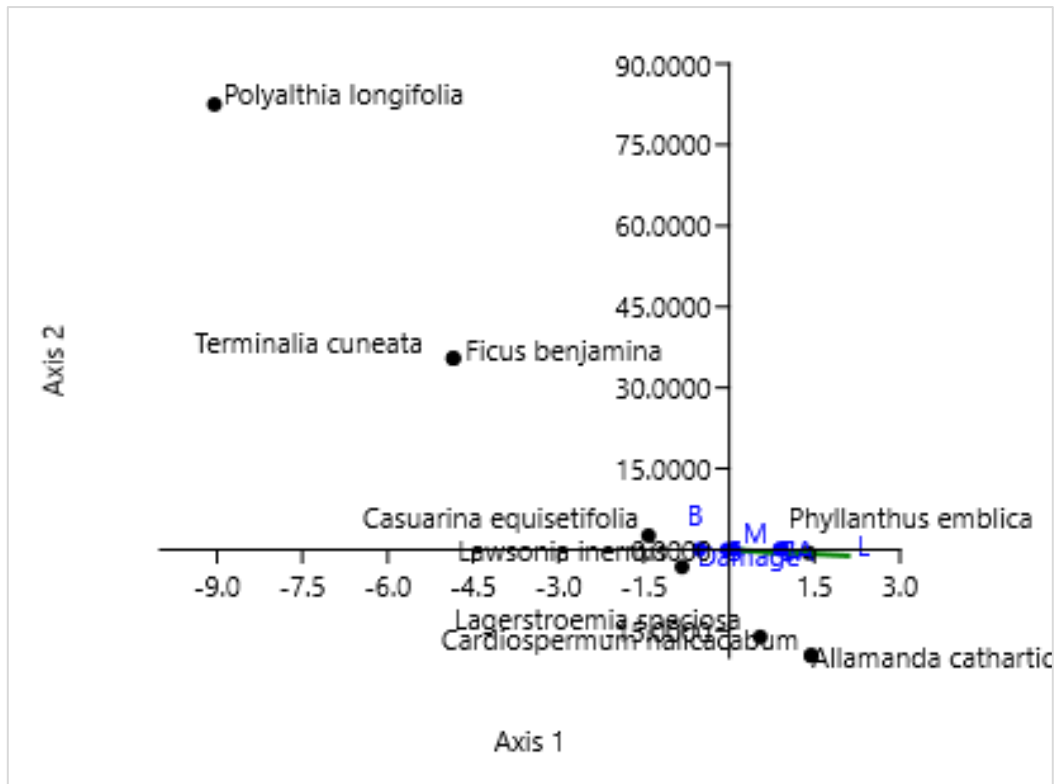


Figure 30: PCA analysis of bag positioning and damage by *Clania holmesi c f*

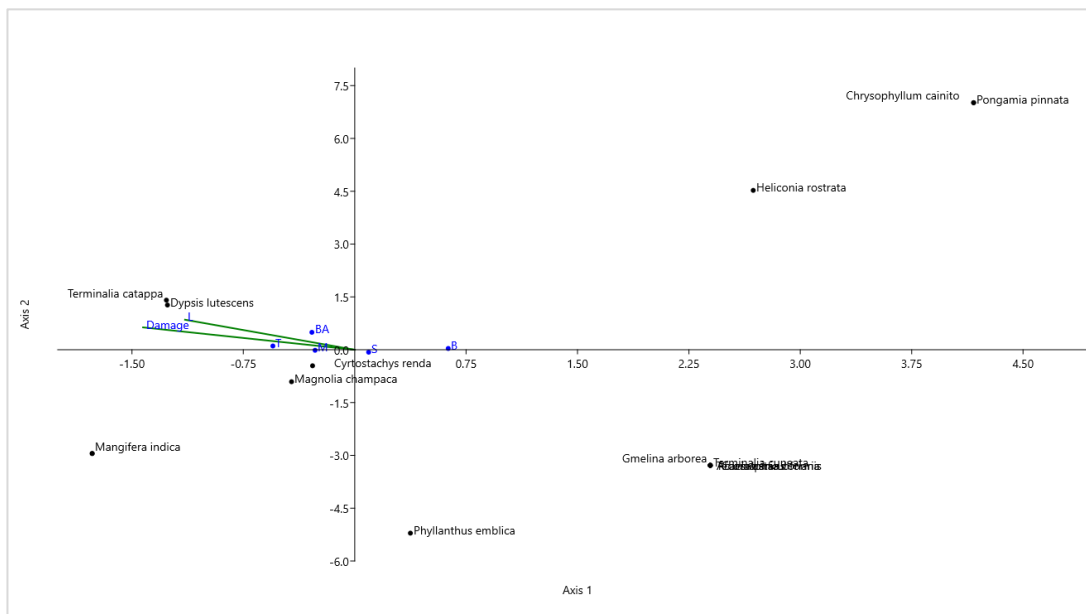


Figure 31: PCA analysis of bag positioning and damage by *Metisa canifrons*

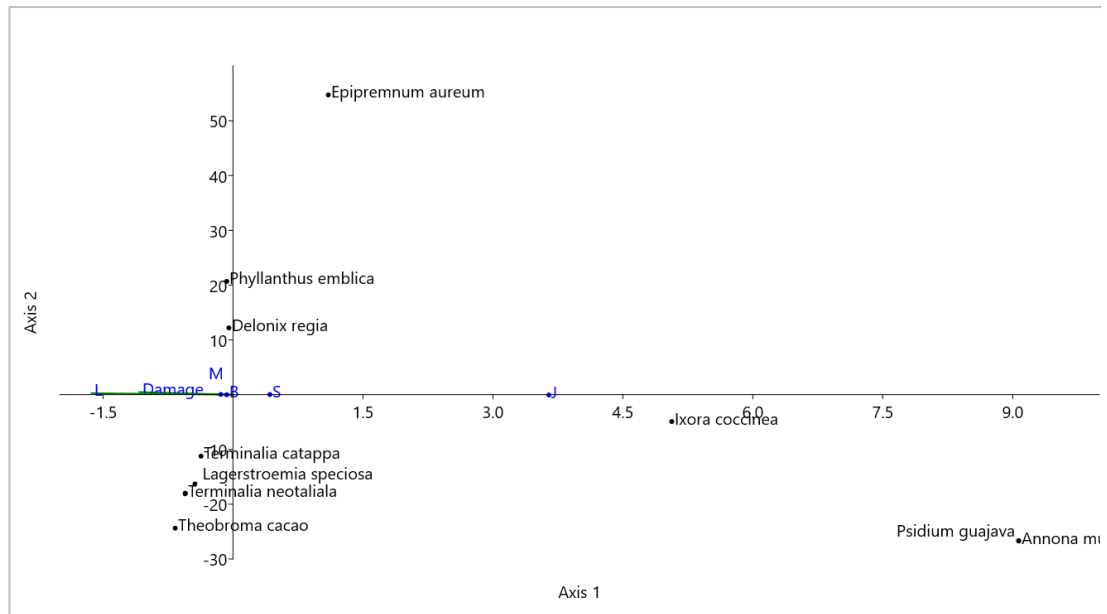


Figure 32: PCA analysis of bag positioning and damage by *Pteroma plagiophleps*

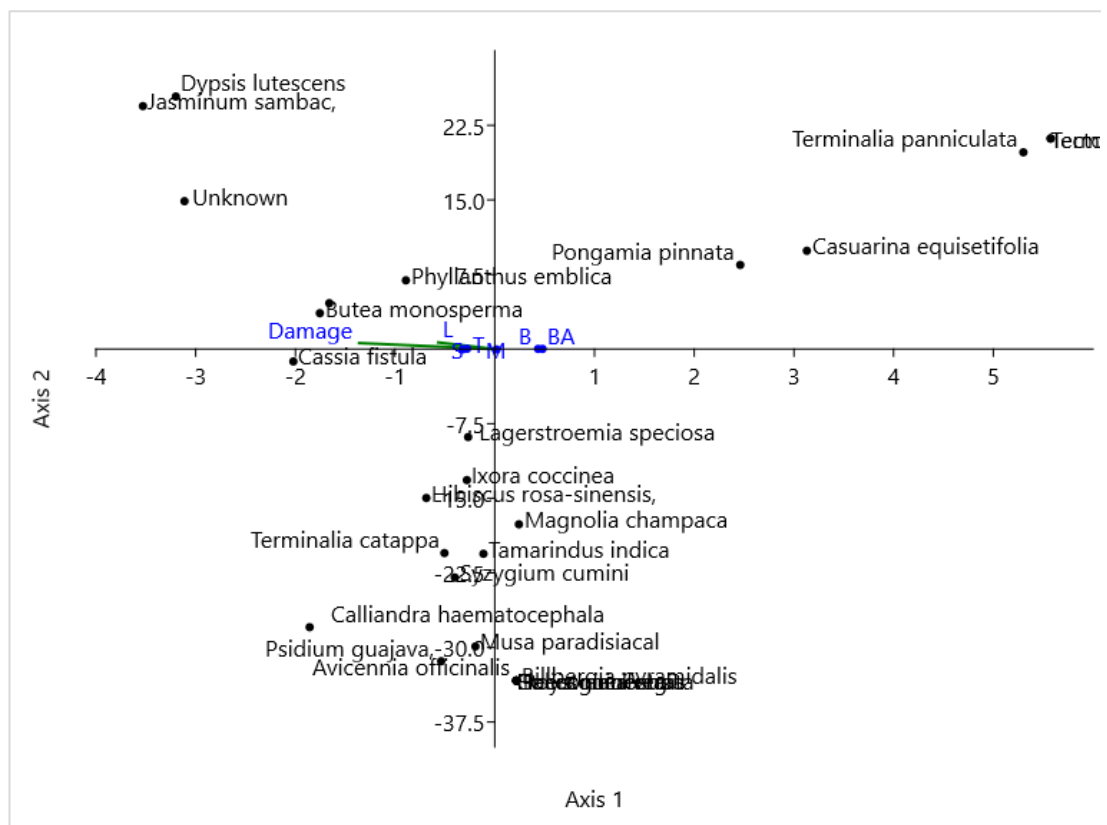


Figure 33: PCA analysis of bag positioning and damage by *Manatha albipes*

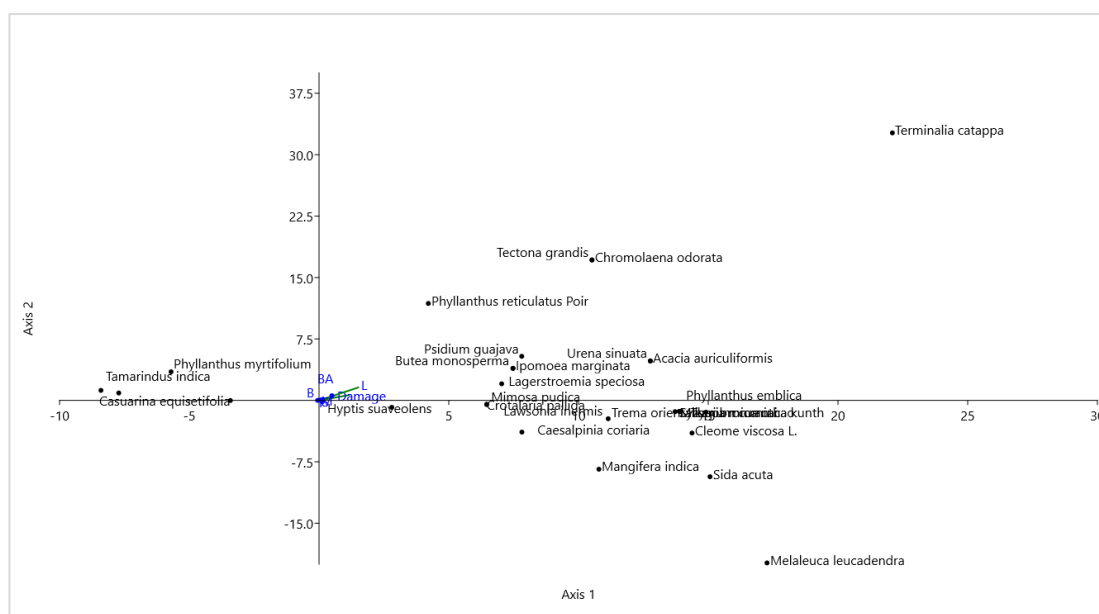


Figure 34: PCA analysis of bag positioning and damage by *Eumeta crameri*

5.4.2. Distribution mapping of all species

All districts of Kerala were surveyed for bagworm infestations, based on which distribution mapping of all the species was done. The total land area of Kerala is 38,863 sq km.

The presence of pest species such as *Manatha albipes*, *Pteroma plagiophles*, *Eumeta crameri*, *Metisa plana* and *Metisa canifrons* was seen in almost all in the districts. The habitat specific species such as *Eumasia thomasii*, *Eumasia venefica* and *Capulopsyche keralensis* have isolated distribution and were spotted only from one or two places during the study.

The northernmost report of *Acanthoecia larminati* was from Banasursagar dam, Wayanad and the southernmost report was from Konni, Pathanamthitta. The distance between these two points was 274 km. The distance between the easternmost (Chavakkad, Thrissur) and westernmost (Eastfort, Thrissur) observation sites was 119.6 km. A polygon drawn using these points as vertices covered an area of 6518 sq. km which is 16.77% of Kerala's land area.

The northernmost report of *Acanthopsyche alstoni* was Kattikulam, Wayanad and the southernmost from report was Nariyampara, Idukki. The distance between these two points was 238.6 km. The distance between the easternmost (Mambaram, Palakkad) and westernmost (Edakkazhiyoor, Thrissur) observation sites was 142.3 km. A polygon

drawn using these points are vertices covering an area of 12110 sq. km which is 31.16 % of Kerala's land area.

Table 13: Distribution of bagworm species in Kerala

Species name	North-south	East-west	Total Area of infestation in km²	The number of districts from where the species collected	Fig. number of species distribution map
<i>Acanthoecia larminati</i>	274 km	119.6 km	6518	07	37
<i>Acanthopsyche alstoni</i>	238.6 km	142.3 km	12110	03	38
<i>Acanthopsyche cana</i> and <i>Acanthopsyche sp</i>	453.4 km	222.6 km	16540	14	39
<i>Clania holmesi</i>	450.5 km	219.8 km	20580	10	43
<i>Degiella sp</i>	298.4 km	135.3 km	7771	07	50
<i>Eumeta crameri</i>	451.1 km	221.5 km	20170	13	40
<i>Eumeta variegata</i>	97 km	51 km	-	02	41
<i>Manatha albipes</i>	451.6 km	220.9 km	12230	13	42
<i>Metisa canifrons</i>	338.7 km	134.5 km	11230	10	44
<i>Metisa plana</i>	358.9 km	220.6 km	13730	10	45
<i>Struthisca cf farinosa</i>	199.9 km	79.48 km	2092	04	49
<i>Pteroma plagiophleps</i>	422.3 km	218.5 km	22020	11	46

The northernmost report of *Acanthopsyche cana* and *Acanthopsyche sp* was CPCRI Kasaragod and the southernmost report was from Vellayani, Thiruvananthapuram. The distance between these two points was 453.4 km. The distance between the easternmost (Parali, Palakkad) and westernmost (Wadakkanchery, Thrissur) observation sites was 222.6 km. A polygon drawn using these points as vertices covered an area of 16540 sq. km which is 42.56% of Kerala's land area.

The northernmost report of *Clania holmesi* was CPCRI Kasaragod and the southernmost report was Vellayani, Thiruvananthapuram. The distance between these two points was 450.5 km. The distance between the easternmost (Mambaram, Palakkad) and westernmost (Edakkazhiyoor, Thrissur) observation sites was 219.8 km. A polygon drawn using these points as vertices covered an area of 20580 sq. km which is 52.95% of Kerala's land area.

The northernmost report of *Eumeta crameri* was CPCRI Kasaragod and the southernmost report was Karyavattom, Thiruvananthapuram. The distance between these two points was 451.1 km. The distance between the easternmost (Pothundi dam, Palakkad) and westernmost (Edakkazhiyoor, Thrissur) observation sites was 221.5 km. A polygon drawn using these points as vertices covered an area of 20170 sq. km which is 51.90% of Kerala's land area.

The northernmost report of *Manatha albipes* was CPCRI Kasaragod and the southernmost report was Melaranoor, Thiruvananthapuram. The distance between these two points was 451.6 km. The distance between the easternmost (Malampuzha, Palakkad) and westernmost (Thalikkulam, Thrissur) observation sites was 220.9 km. A polygon drawn using these points as vertices covered an area of 12230 sq. km which is 31.88% of Kerala's land area.

The northernmost report of *Metisa canifrons* was from Soochippara, Wayanad and the southernmost report was Melaranoor, Thiruvananthapuram. The distance between these two points was 338.7 km. The distance between the easternmost (Idukki township) and westernmost (Athani, Ernakulam) observation sites was 134.5 km. A polygon drawn using these points as vertices covered an area of 11230 sq. km which is 28.89% of Kerala's land area.

The northernmost report of *Metisa plana* was CPCRI Kasaragod and the southernmost report was Thottappally, Alappuzha. The distance between these two points was 358.9 km. The distance between the easternmost (Kollankode, Palakkad) and westernmost (Edakkazhiyoor, Thrissur) observation sites was 220.6 km. A polygon drawn using these points as vertices had an area of 13730 sq. km which is 35.33% of Kerala's land area.

The northernmost report of *Pteroma plagiophleps* was CPCRI Kasaragod and the southernmost report was Varkala cliff, Thiruvananthapuram. The distance between these two points was 422.3 km. The distance between the easternmost (Parali, Palakkad) and westernmost (Edakkazhiyoor, Thrissur) observation sites was 218.5 km. A polygon drawn using these points as vertices had an area of 22020 sq. km which is 56.67% of Kerala's land area.

Eumeta variegata was reported from only two sites from two districts, The northernmost report was Pariyaram, Kannur (97 km) and the southernmost report was from the University of Calicut campus (51 km).

The northernmost report of *Struthisca cf. farinosa* was from Aasarikkadu, Thrissur and the southernmost report was Chadayamangalam, Kollam. The distance between these two points was 199.9 km. The distance between the easternmost (Velur, Thrissur) and westernmost (Aasarikkadu, Thrissur) observation sites was 79.48 km. A polygon drawn using these points as vertices had an area of 2092 sq. km which is 5.38% of Kerala's land area.

The northernmost report of *Degiella sp* was Parasinikadavu, Kannur and the southernmost report was Thottapilly, Alappuzha. The distance between these two points was 298.4 km. The distance between the easternmost (University of Calicut campus) and westernmost (ZGC, Kozhikode) observation sites was 135.3 km. A polygon drawn using these points as vertices had an area of 7771 sq. km which is 19.99% of Kerala's land area. Details are given in Table 13.

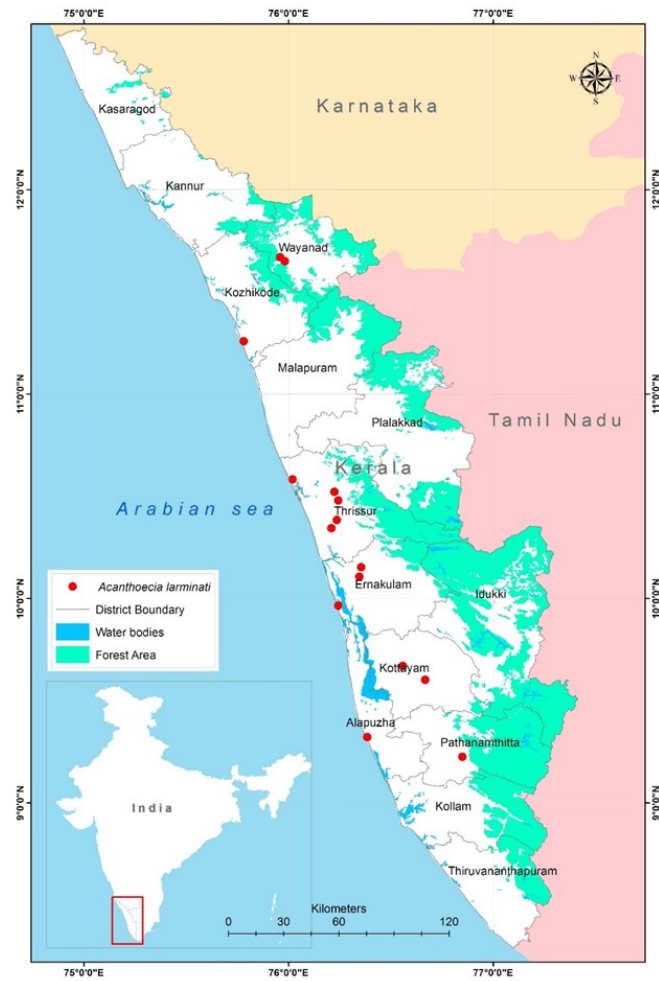


Figure 35: Distribution map of *Acanthoecia larminati*

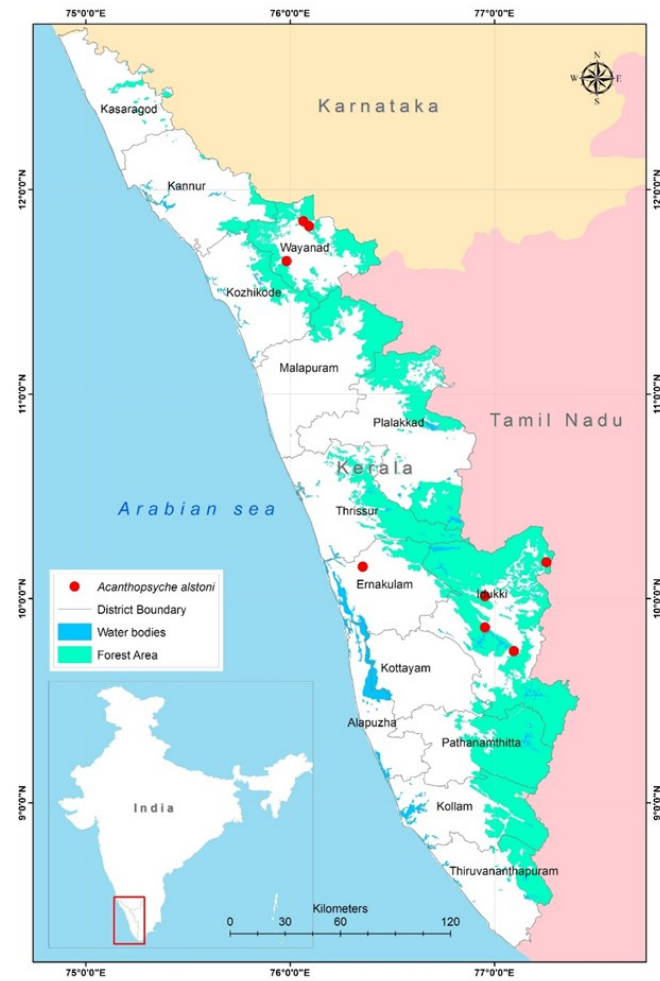


Figure 36: Distribution map of *Acanthopsyche alstoni*

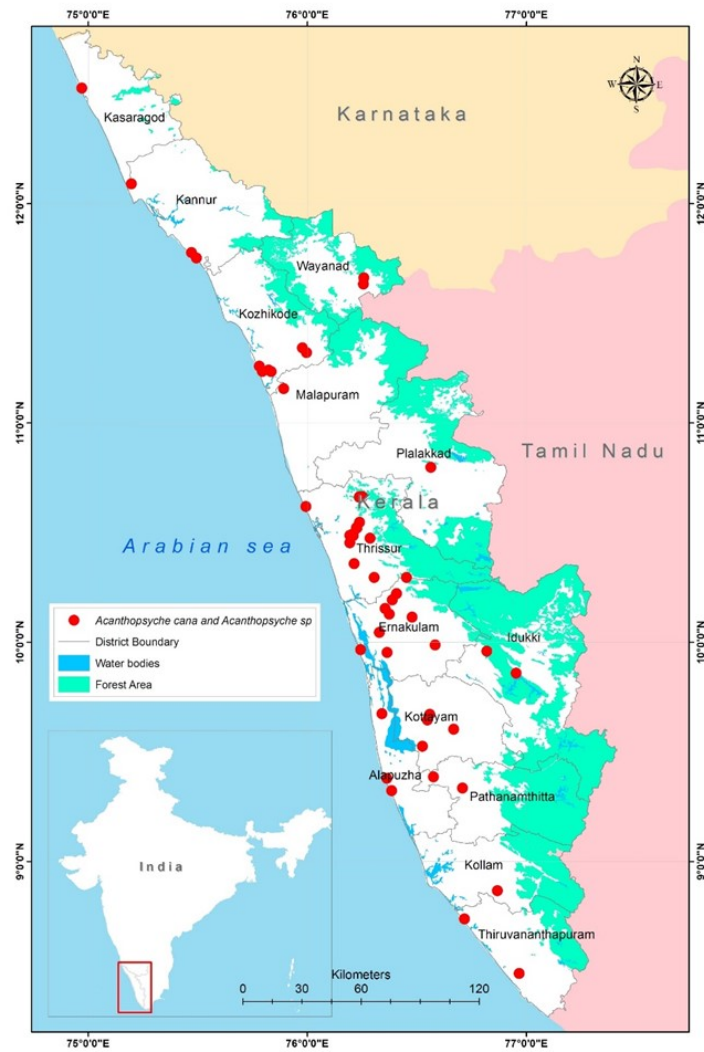


Figure 37: Distribution map of *Acanthopsyche cana* and *Acanthopsyche* sp.

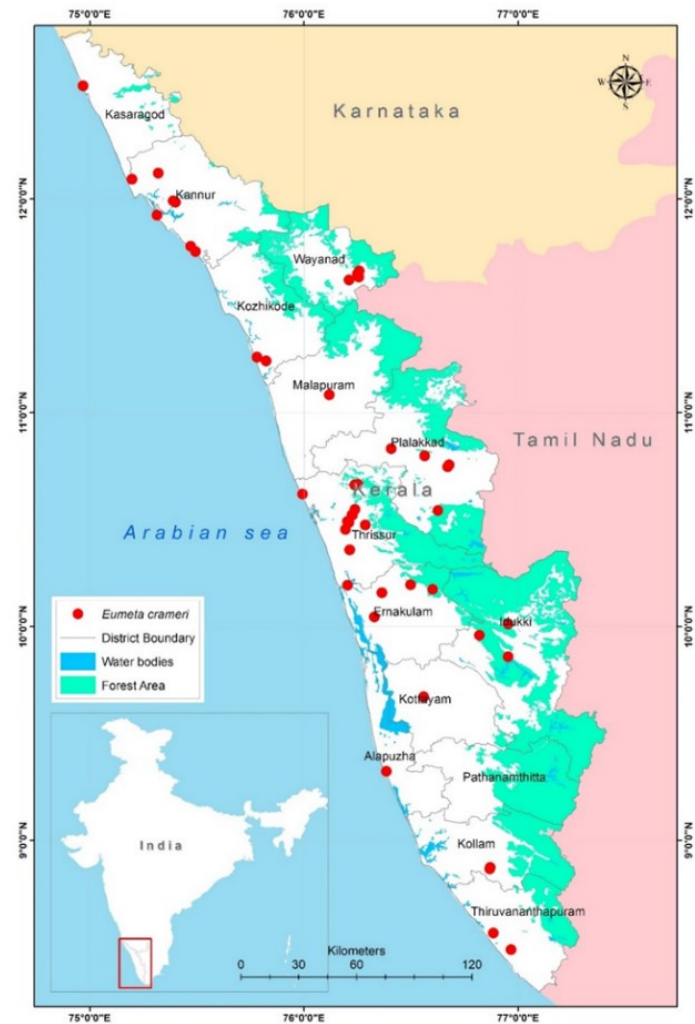


Figure 38: Distribution map of *Eumeta crameri*

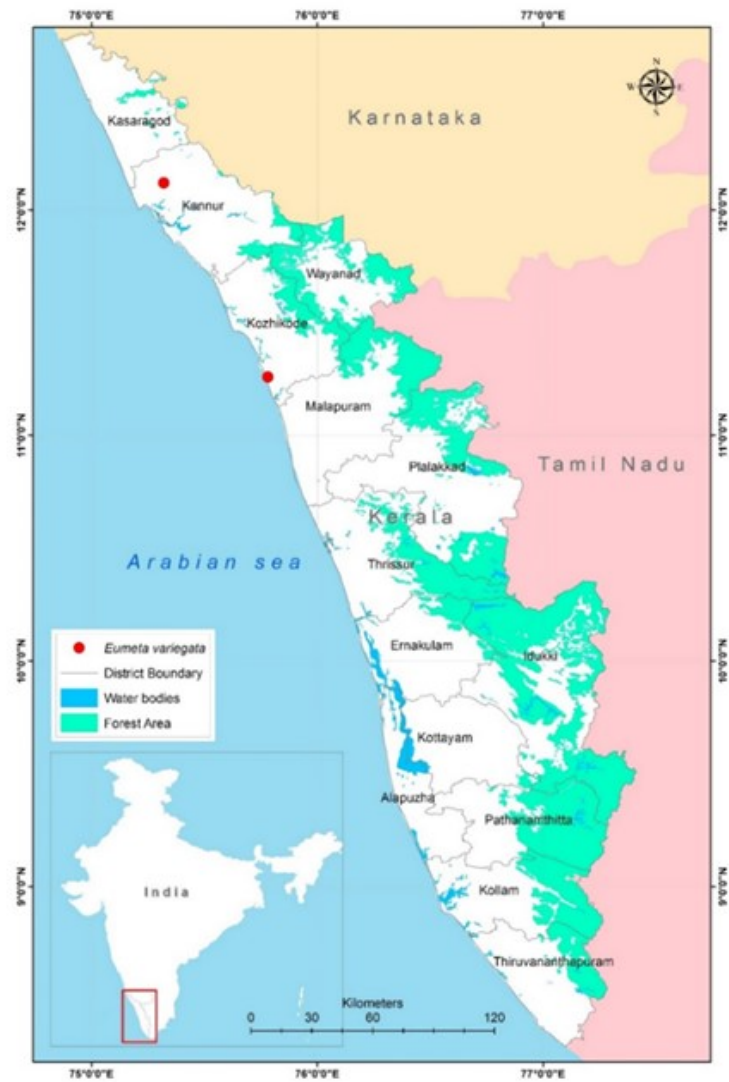


Figure 39: Distribution map of *Eumeta variegata*

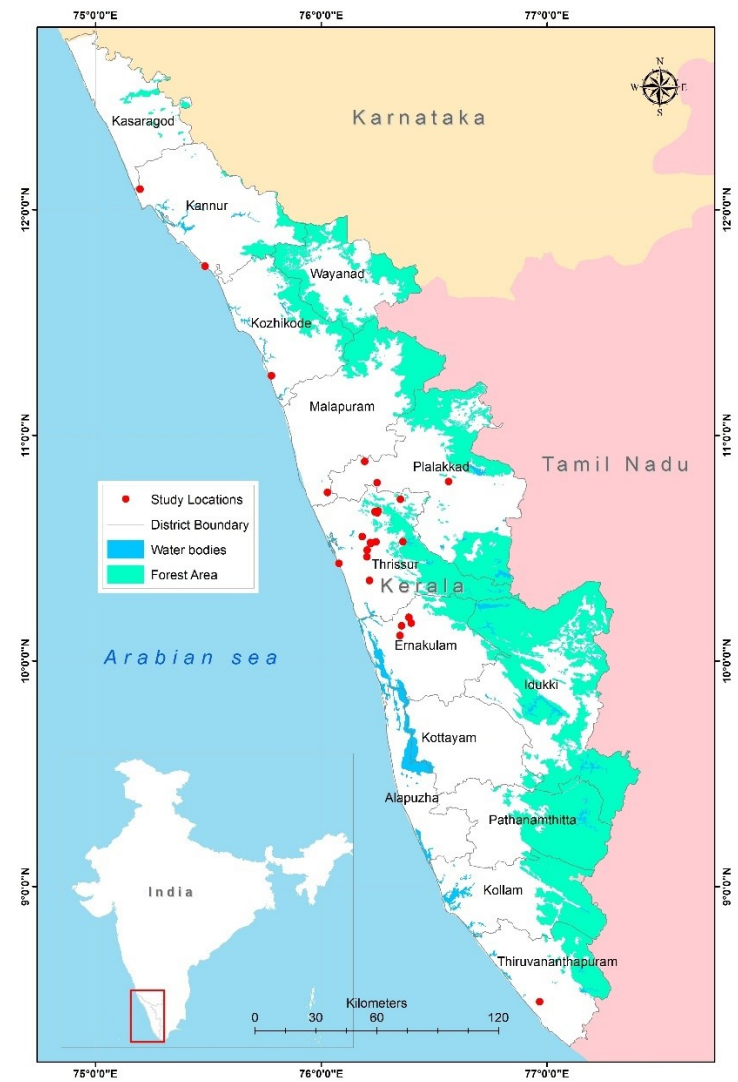


Figure 40: Distribution map of *Manatha albipes*

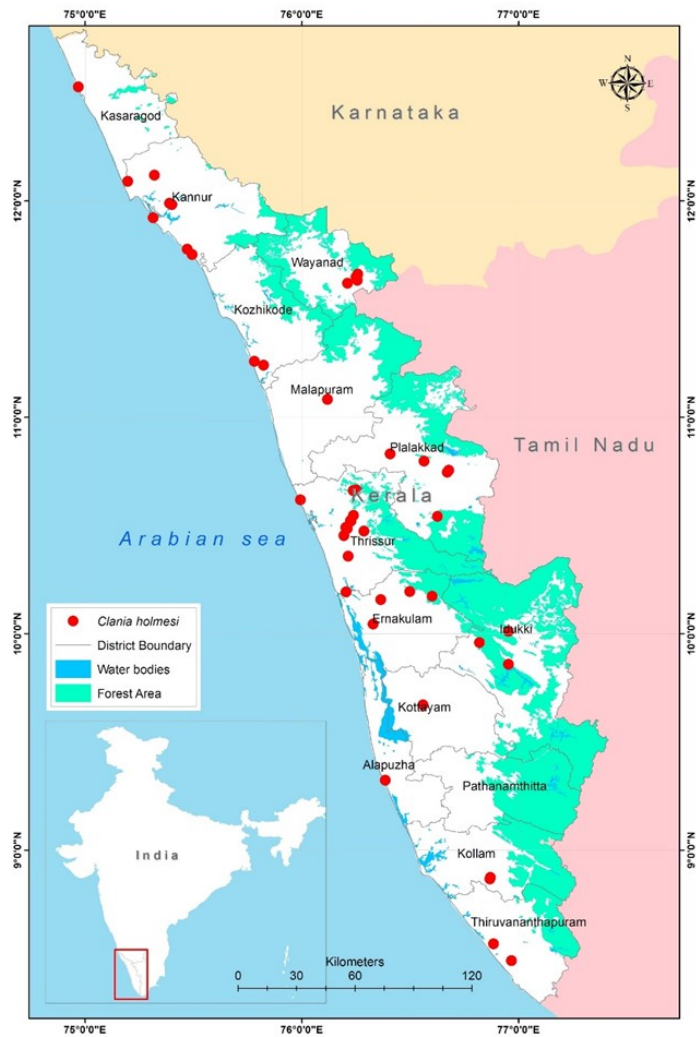


Figure 41: Distribution map of *Clania holmesi* (incertae sedis)

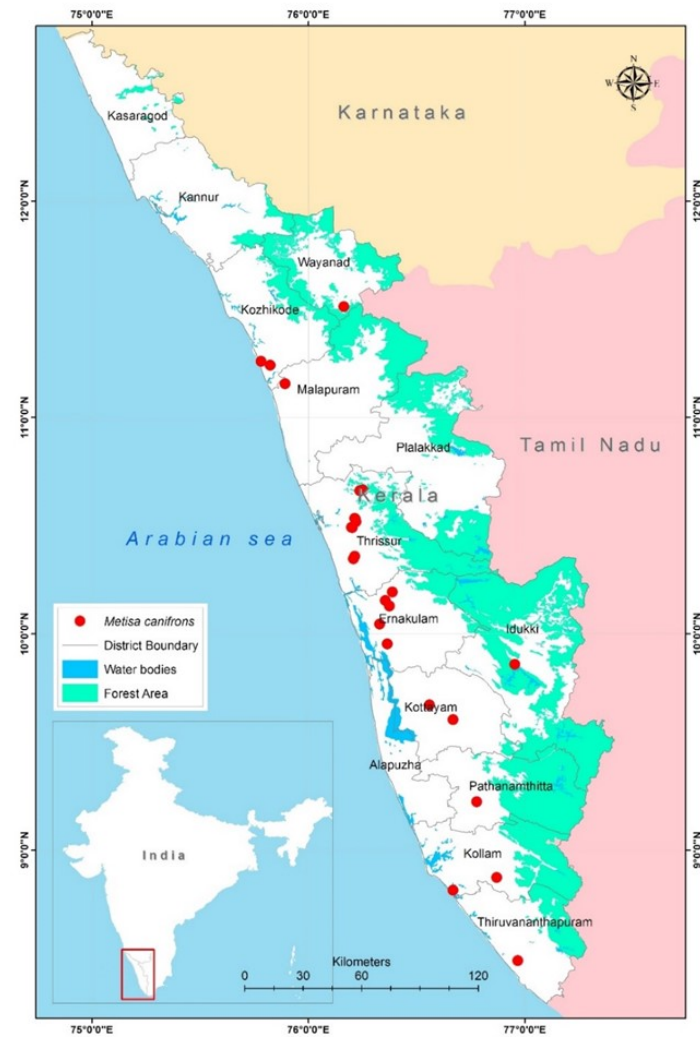


Figure 42: Distribution map of *Metisa canifrons*

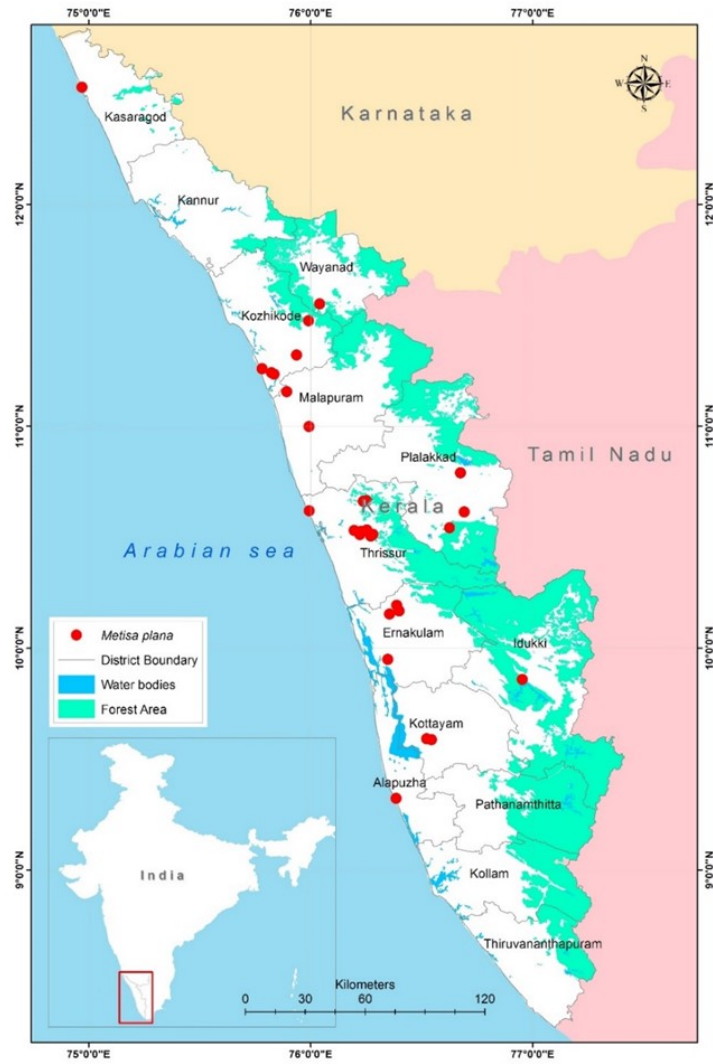


Figure 43: Distribution map of *Metisa plana*

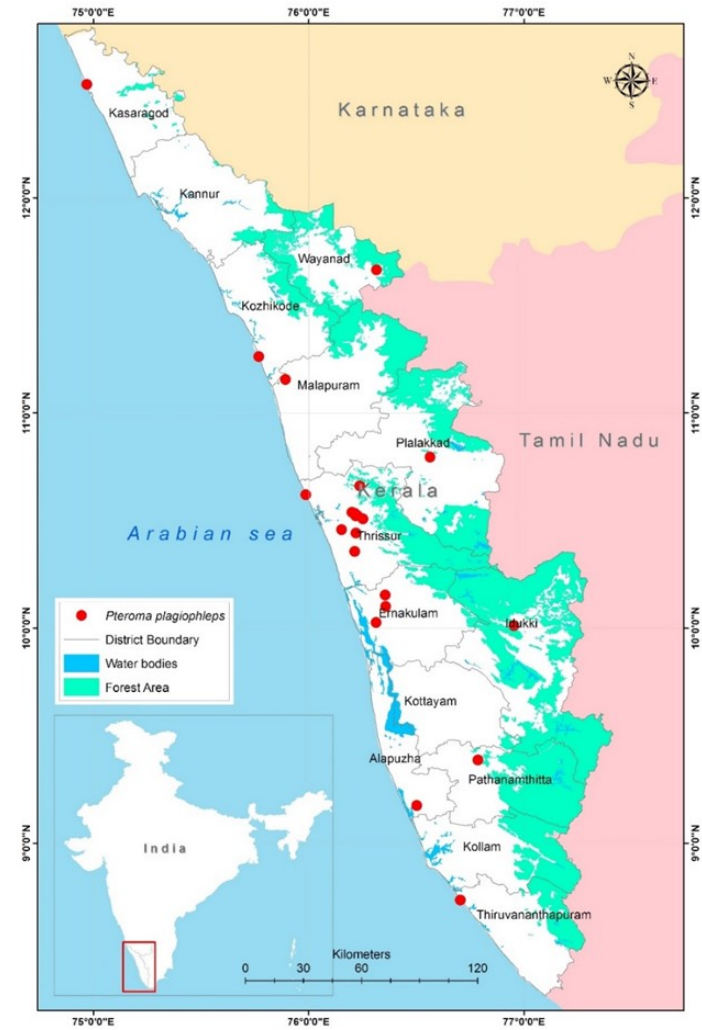


Figure 44: Distribution map of *Pteroma plagiophleps*

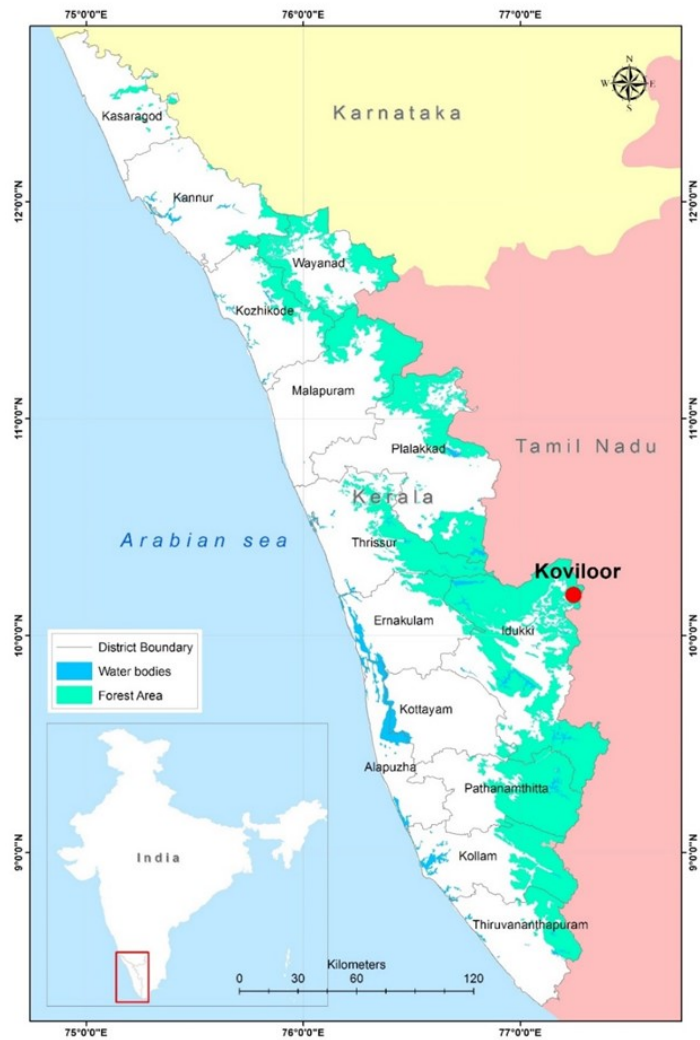


Figure 45: Distribution map of *Eumasia thomasi*

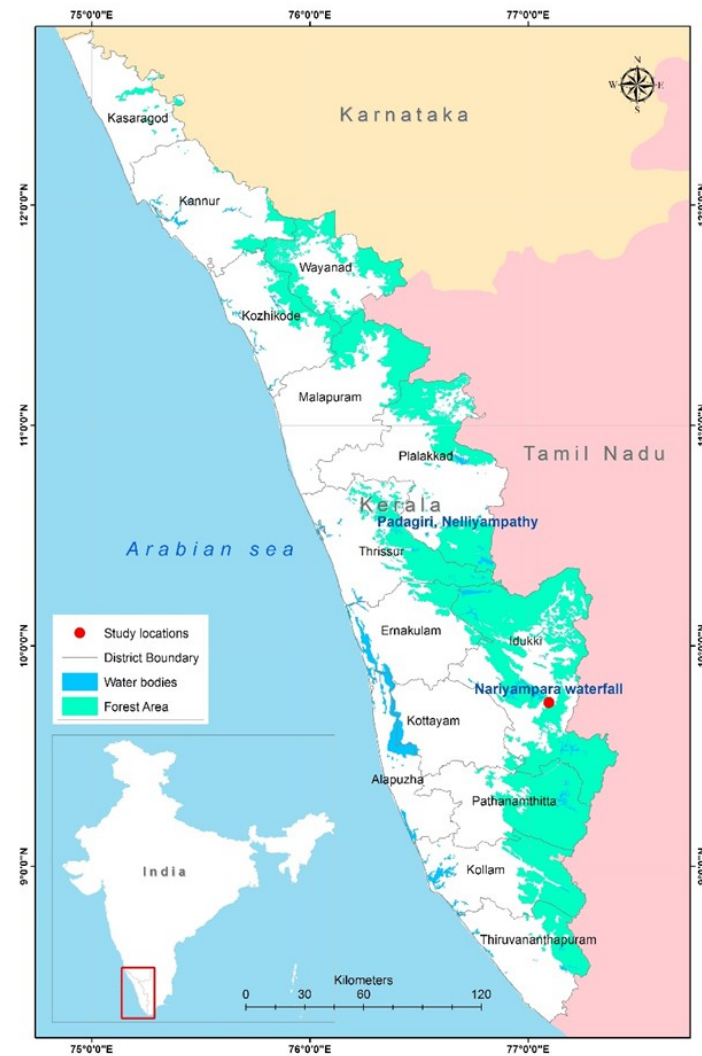


Figure 46: Distribution map of *Eumasia venefica*

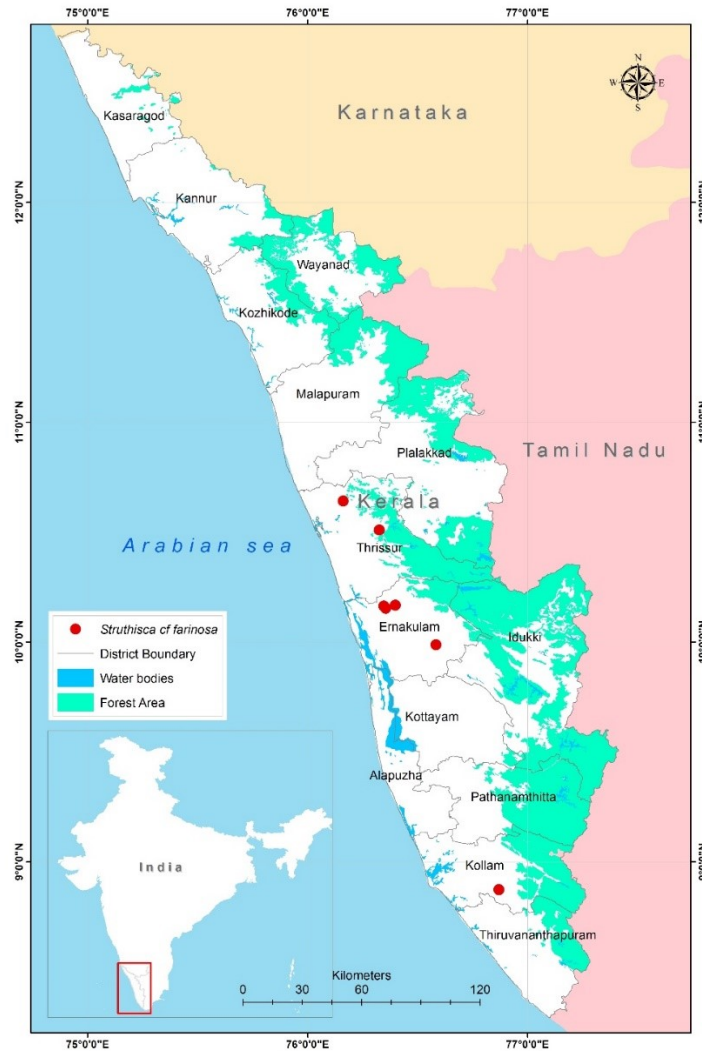


Figure 47: Distribution map of *Struthisca cf farinosa*

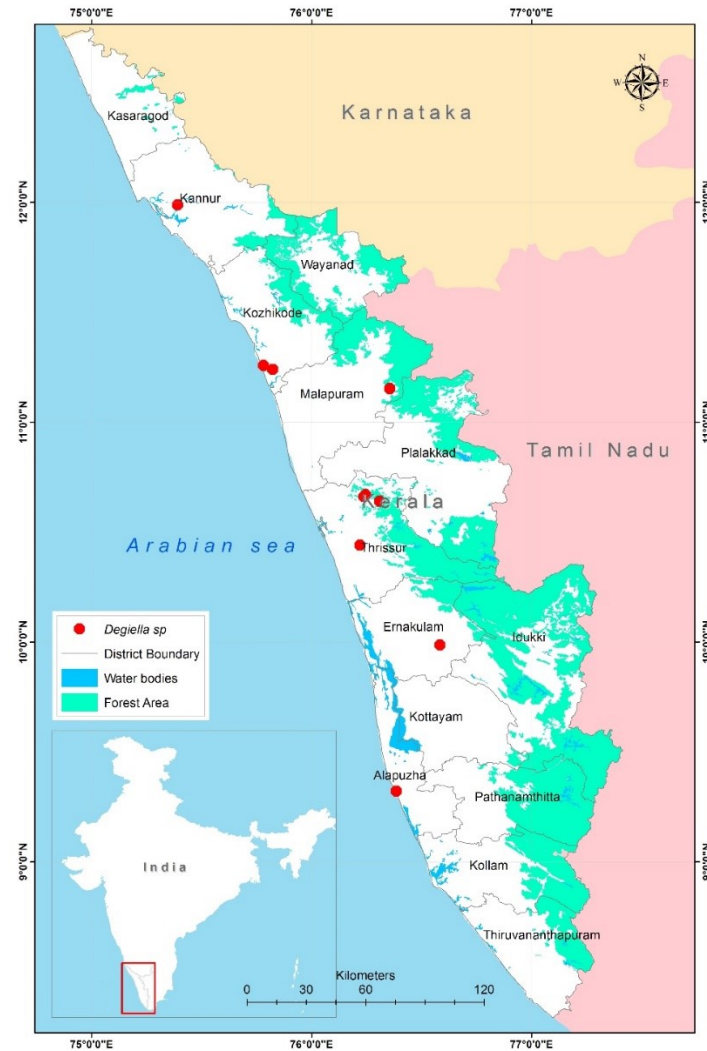


Figure 48: Distribution map of *Degiella sp. nov.*

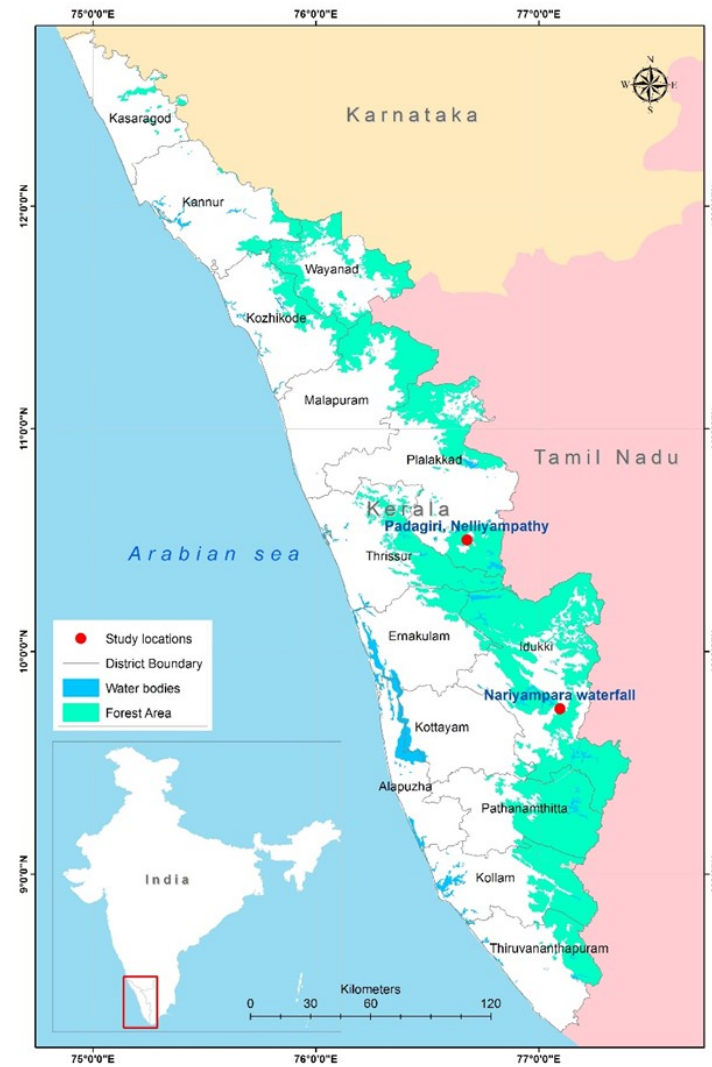


Figure 49: Distribution map of *Capulopsyche keralensis*

5.4.3. Threat analysis of selected species

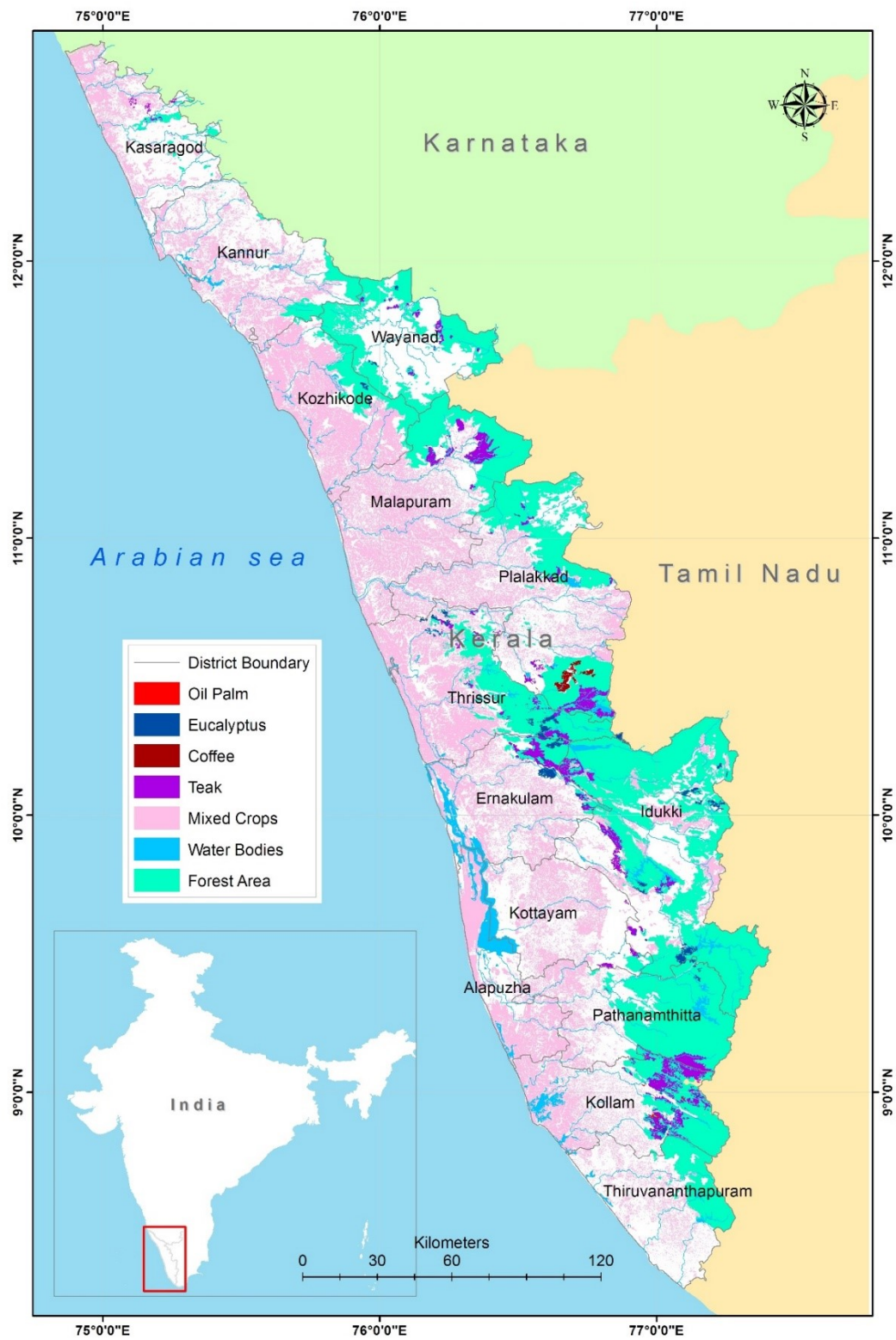


Figure 50: Map showing high risk areas of bagworm infestation based on land use

Seven species showed pestilence by causing damage to host plants, ie; *Eumeta crameri*, *Manatha albipes*, *Metisa plana*, *Metisa canifrons*, *Acanthopsyche cana*, *Acanthopsyche* sp. and *Pteroma plagiophleps*. All these species were recorded in areas under mixed and monoculture plantations of banana, areca nut, and coconut, teak, eucalyptus, pepper and oil palm. The map of regions showing high potential for bagworm attack (Fig. 50) showed that almost the entire cultivated region of Kerala was prone to such attacks. Major economically important crops based on land use maps showed 528.99 km² was planted with bananas; 957.39 km² were used for areca nut farming; oil palm plantations had 4.128 km²; teak under 853.6 km²; eucalyptus planted under 189.5 km² and coffee cultivated in 45.33 km². This is only a minimum estimate because it does not include areas inside forest or cultivated areas not yet updated in land use maps. The land areas of mixed crops and other monoculture plantations covered almost the entire land of Kerala, which indicates high threat of bagworm infestations if all other factors such as temperature and humidity became favourable. Many species of hostplant overlap each other.

The pestilence of insects are increased due to favourable environmental conditions, such as temperature, humidity, rain fall etc. The bagworms are preferred high temperature and low humidity for their survival. And the climatic conditions of Kerala where high humidity and rainfall is a major characteristic is less favourable for the propagation of the bagworms in Kerala. The presence of natural enemies of bagworms like parasitoids and predators may also be controlling the populations of these insects.

5.4.4. Natural enemies of bagworms

Interaction of various kinds of animals with bagworms were observed during the study. These animals could be classified as predators, parasitoids and neutral interactors.

a) Parasitoids (Plate 30)

Parasitoids attack bagworms during their larval instars and pupal stages. They lay eggs on the larvae and pupae by entering their larval bags. The host bagworms are killed when the parasitoids' eggs hatch into larvae. Eighteen different species of parasitoids from Diptera and Hymenoptera were found infesting 10 species of bagworms. These include eight Hymenopteran families and one Diptera family. Parasitoids infestations were found from bagworms collected from seven different species of host plants.

The greatest number of parasitoid attacks was observed in *Manatha albipes*. Nine species from five families of parasitoids were obtained from the bags of *Manatha albipes*. They were *Chirotica decorata*, *Paraphylax sp.* (both from Ichneumonidae), *Elasmus hutsoni*, *Pediobius sp.* (Eulophidae), *Brachymeria cf prodeniae*, *Brachymeria sp.* (Chalcididae), *Eurytoma sp.*, one unknown species (Eurytomidae) and one unknown species from the family Eupelmidae.

Four different parasitoid species were recorded in *Eumeta crameri* which included the Dipteran parasitoid *Nealsomyia rufipes*. Two species were recorded in *Acanthoecia larminati* such as cf *Lysitermus sp.* (Braconidae) and one unknown species from Ichneumonidae. *Degiella sp.*, *Acanthopsyche alstoni*, *Acanthopsyche cana* and three unidentified bagworm species were found to be infested by one parasitoid each (Table 14).

Most number of parasitoid species were recorded from the family Ichneumonidae (04), following Eulophidae and Chalcididae (03 each), Braconidae (02), Eurytomidae (02), Bethyridae (01), Eupelmidae (01), Vespidae (01), and Tachinidae (01).

b) Predators

The major predators of bagworms were ants. Four different species of ants such as *Camponotus sp.*, *Oecophylla sp.*, *Tapinoma melanocephalum* and one unidentified species were frequently attacking bagworms were observed during the larval rearing. They frequently attack the female bags containing eggs and eats their eggs. They also attacks larvae and male pupae.

Table 14: Hymenopterans and Dipterans associated with bagworm species and their host plants

Order	Superfamily	Parasitoid family	Name of the parasitoid	Host species	Host plants	Remarks
Hymenoptera	Chalcidoidea	Ichneumonidae	<i>Chirotica decorata</i>	<i>Manatha albipes</i>	<i>Pongamia pinnata</i>	Parasitoid
				Unidentified sp.		
			<i>Ichneumonid</i> sp.	<i>Acanthoecia larminati</i>	Nil	Parasitoid
				Unidentified sp.		
			<i>Goryphus nursei</i>	<i>Eumeta crameri</i>	<i>Hyptis suaveolens</i>	Parasitoid
			<i>Paraphylax</i> sp	<i>Manatha albipes</i>	<i>Tamarindus indicus</i>	Parasitoid
		Braconidae	<i>Chelonus</i> sp.	<i>Degiella</i> sp.	Nil	Parasitoid
			<i>Lysitermus</i> sp. cf	<i>Acanthoecia larminati</i>	Nil	Parasitoid
		Eulophidae	<i>Elasmus</i> sp. nov	<i>Acanthopsyche alstoni</i>	<i>Ficus benamina</i>	Parasitoid
			<i>Elasmus hutsoni</i>	<i>Manatha albipes</i>	<i>Tamarindus indicus</i> , <i>Syzygium samarangense</i>	Parasitoid
				Unidentified sp. 3		

Order	Superfamily	Parasitoid family	Name of the parasitoid	Host species	Host plants	Remarks
Diptera			<i>Pediobius</i> sp	<i>Manatha albipes</i>	<i>Pongamia pinnata</i>	Parasitoid
		Chalcididae	<i>Brachymeria cf prodeniae</i>	<i>Manatha albipes</i>	<i>Cassia fistula</i>	Parasitoid
			<i>Kriechbaumerella</i> sp.	<i>Acanthopsyche cana</i>	Nil	Parasitoid
			<i>Brachymeria</i> sp.	<i>Manatha albipes</i> ,	<i>Pongamia pinnata</i>	Parasitoid
				<i>Eumeta crameri</i>		
		Eurytomidae	Unknown sp.	<i>Manatha albipes</i>	<i>Pongamia pinnata</i>	Parasitoid
			<i>Eurytoma</i> sp.	<i>Manatha albipes</i>	<i>Pongamia pinnata</i>	Parasitoid
		Eupelmidae	Unknown sp.	<i>Manatha albipes</i>	<i>Pongamia pinnata</i>	Parasitoid
	Chrysidoidea	Bethylidae	<i>Goniozus</i> sp.	Unidentified sp.	Nil	Parasitoid
	Vespoidea	Vespidae	<i>Knemodynerus</i> sp.	<i>Eumeta crameri</i>	<i>Hyptis suaveolens</i>	Predator
Diptera	Oestroidea	Tachinidae	<i>Nealsomyia rufipes</i>	<i>Eumeta crameri</i>	<i>Mangifera indica</i>	Parasitoid

Another predator of bagworms is the common babbler bird (*Turdoides caudata*). The bird eats bagworm larvae from its bags. The birds feeding on the larvae of *Eumeta crameri* and *Manatha albipes* were observed in the field.

c) Others

Many insects are associated with bagworms in a different manner and most of them are harmless to the insect, such as spiders and beetles. Attacks of booklice on older larval or pupal bags of bagworm were seen especially in stored bags. They feed the bag material and destroy it. The storage of older bags becomes challenging because of booklice attacks.

Parasitoids and predators are considered to be the control agents of bagworm population (Hardenberg, 1919; Mathew, 1989). This is a preliminary data on the parasitoids of the bagworm reported from the study area. Further studies are recommended to understand the predator- parasitoid dynamics with bagworms which can be used for formulating pest control measures.

5.5. Discussion

Most Bagworms are poly phytophagous in nature. According to experimental and theoretical studies, herbivory rates ought to increase significantly as temperature increases (O'Connor, *et al.*, 2011). So, the climatic conditions in the habitat have much influence on the survival of the bagworms. In the larval stage, the bagworms prefer small plants for their feeding, they eat leaves of herbs and shrubs mostly and cause severe loss of foliage in plants. Sometimes plants only act as substrates for the pupal bag attachment.

The last instars of *Eumeta crameri* migrate to trees after feeding on herbs and shrubs in the early instars. Similar behaviour has been seen in *Acanthopsyche* species, *A. cana*, *A. alstoni*, one unidentified species. In *Manatha albipes* the larval stages prefer plants such as herbs and shrubs for feeding and the pupal bags of these insects were mostly seen attached on the bottom regions of the trees or plants and other hard substrates such as walls. The huge number of pupal bags segregating on the tree trunk regions was observed in *Manatha albipes*. In *Petroma plagiophleps* the feeding is observed mostly on leaf tissues and larval bags are remained attached on the surfaces of the leaves. For

pupations they prefer the underside of the leaves, tree branches and twigs over tree trunk region.

Bag positioning could be a survival technique. The relative size of the bags collected from the trees and reduced feeding (less damage observed) shows that mature larvae mostly prefer to move to trees before pupation in the case of *Eumeta crameri*. This could indirectly help in better dispersal of the larvae, as air currents assist the ballooning technique used by larvae for dispersal. While larval bags do not show any special preference for the top, middle, or lower parts of the host plant, and they are actively moving all the plant area, last instar bags remained in the top region and were not observed to move much in *Eumeta crameri* (Usha *et al.*, 2021).

Many previous studies (Poorani *et al.*, 2022; Usha *et al.*, 2022b; Wood and Kamarudin, 2019; Kamarudin & Arshad, 2016; Cheong *et al.*, 2010; Kamarudin *et al.*, 1996; Hardenberg, 1919; Mathew, 1989) have discussed the presence of parasitoids associated with bagworms. A vast array of parasitoids was recovered from the bags of Psychidae in the study region. Only eighteen species could be identified till genus level as identification of these were not in the direct purview of this study. Based on field experiences and review of previous literature, parasitoids of bagworms could be recommended as a topic of intensive study. Such knowledge could be used for natural pest control measures.

Each Bagworm species showed some uniqueness in hostplant selection, feeding and bag attachment. These observations could be unique to the region as the bagworm behaviour may be influenced by climatic conditions and host plant availability. There are no previous studies to compare such data even though such information is essential to formulate pest control measures.

5.6. Conclusion

The study listed seventy-three hostplant species belonging to thirty-eight families which were infested by nine poly phytophagous bagworm species from the study area. Most species showed voracious feeding on plants and caused damage but some species depended on the plants only for their pupal bag attachment. Early instar larvae preferred herbs and shrubs for feeding and final instars used trees for attachment of their pupal

bags. Bagworms and their recorded hostplants were distributed all over the state of Kerala. In spite of infestations in agricultural lands, large scale damage was isolated to a few cases only. It is hypothesized that unfavourable climatic conditions, natural enemies, and the unique life history traits of bagworms are keeping its population in check in Kerala.

Further studies and surveys are recommended to get a complete ecological perspective of Psychidae as such data in tandem with climatic and land use change data will help to control these potential pests or even predict outbreaks in advance.

PLATE 27

Bagworms and Host plants



Figures: a. *Acanthopsyche cana* on *Phyllanthus myrtifolius*, b. *Acanthopsyche* sp. on *Hydrangea macrophylla* c. Unidentified bagworm on *Cocos nucifera* d. *Clania holmesi* on *Phyllanthus myrtifolius*, e. *Eumeta crameri* on *Phyllanthus emblica*, f. *Clania holmesi* on *Lawsonia inermis*.

PLATE 28

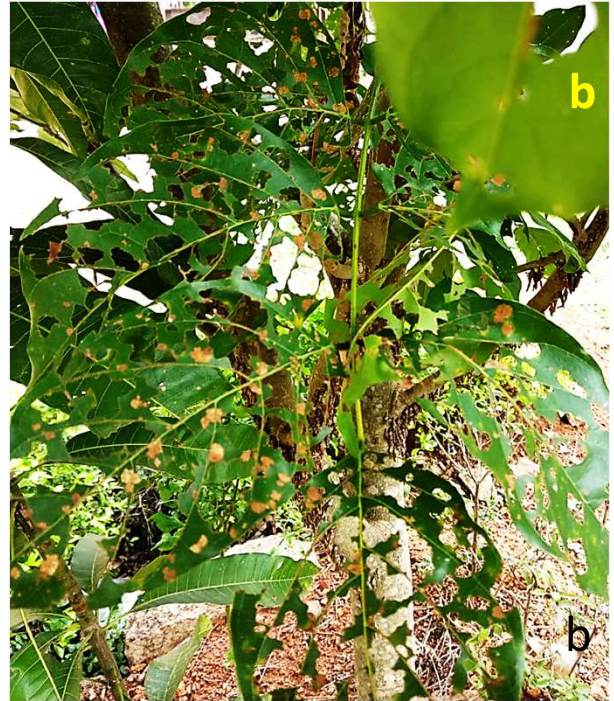
Host plant infestations by Bagworms



Figures: a. Complete defoliation of *Phyllanthus emblica* tree by the infestation of *Pteroma plagiophleps*, b. Damage on *Dypsis lutescens* by *Manatha albipes*, c. Damage on *Lagerstroemia speciosa* by *Manatha albipes* and one unidentified bagworm species, d. Damage of the leaves of *Syzygium samarangense* by *Manatha albipes*.

PLATE 29

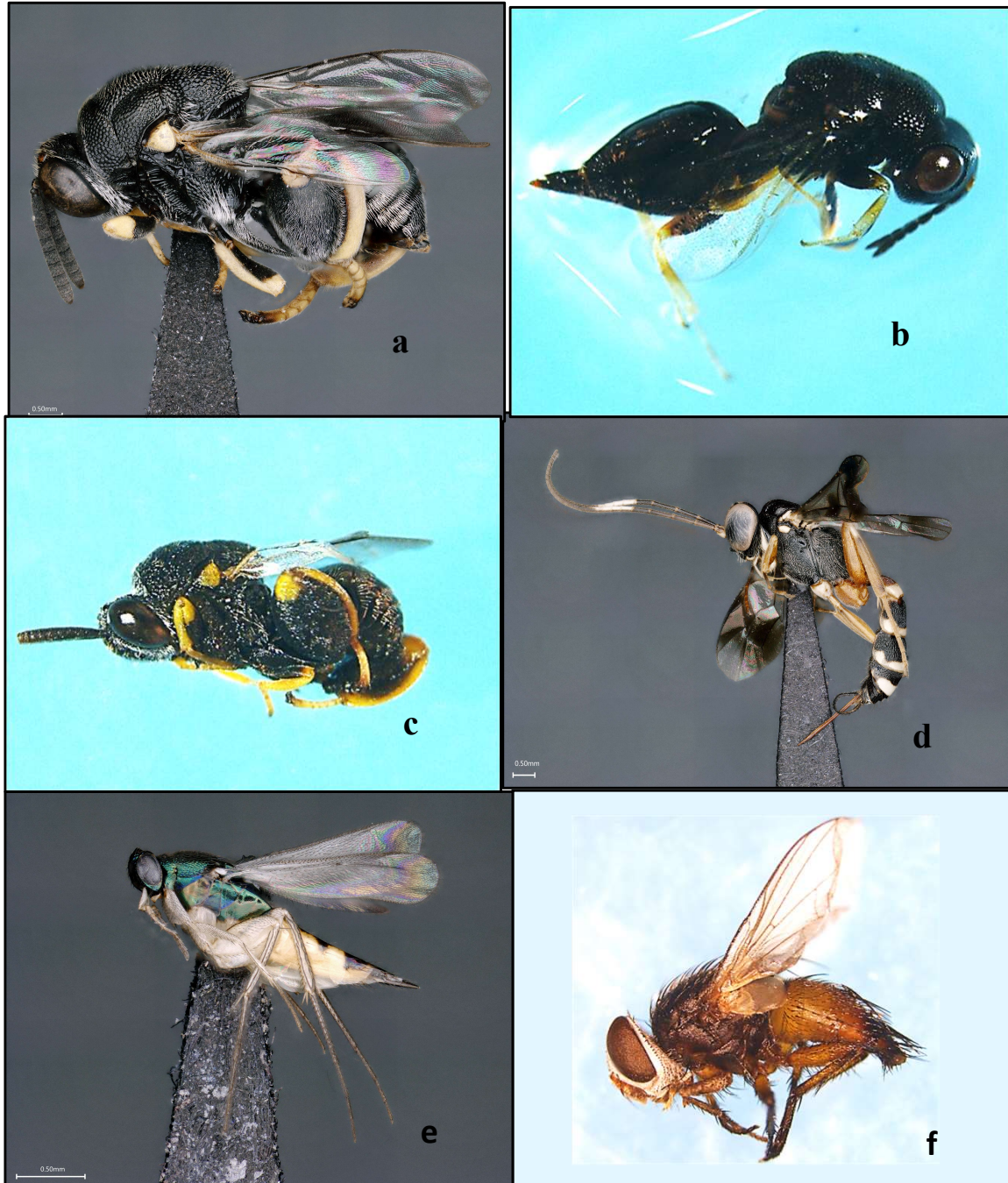
Host plant infestations by Bagworms



Figures: **a.** Infestation of *Manatha albipes* on the leaves of *Syzygium samarangense* **b.** Infestation of *Manatha albipes* on *Pongamia pinnata* , **c.** Massive attachment of the pupal bags of *Manatha albipes* on the trunk region of *Pongamia pinnata*, **d.** Damage on leaves of *Lagerstroemia speciosa* by *Pteroma plagiophleps*

PLATE 30

Selected parasitoids infesting bagworms from the study area



Figures: a. *Brachymeria* cf *prodeniae* ♀, b. *Eurytoma* sp, c. *Brachymeria* sp, d. *Chirotica decorata* , e. *Elasmus* sp. ♀ , f. *Nealsomyia rufipes*

CHAPTER 6

Life cycle studies of selected bagworm species

CHAPTER 6

Life cycle studies of selected bagworm species

6.1. Introduction

Bagworms follow a unique life cycle, with most female adults completing their life and reproductive activities within their bags themselves. Males emerge as winged moths and they search females for mating by approaching female bags. The males are attracted to female bags by the pheromone-impregnated scales (hairs) produced and released into the lower end of the female bags (Stephens, 1962; Davis, 1964; Bosman & Brand, 1971; Leonhardt *et al.*, 1983; Acosta, 1986; Neal, 1981; Loeb *et al.*, 1989). Studies on the morphology of different stages such as egg, larvae, bags, pupae, and adults are very much described in some studies but these studies focus on a single species or a single genus, especially on male adults in a restricted region (Davis, *et al.*, 2008, Hardenberg, 1919). Life cycle studies have immense importance from the perspective of bagworms as pests of many crops, with the larval stages being the most dangerous because of their polyphagous behaviour.

This chapter discusses the life cycle studies of selected bagworm species (*Eumeta crameri* & *Metisa plana*) in the study area and discusses the status of other species collected.

6.2. Review of Literature

Bagworms voraciously feed on tender leaves and twigs at their early instars causing more loss of major growing parts of a plant which in turn will decrease the crop yield (Rhainds *et al.*, 2009). The life cycle and economic importance of Wattle bagworm, which severely attacks wattle plantations in South Africa was described by Hardenberg (1919). Comprehensive studies on the biology and morphology of the life stages of *Perisceptis carnivora* were done in Panama (Davis *et al.*, 2008).

Many studies have been conducted on the life history of bagworms worldwide, *Eumeta crameri* Westwood (Ameen & Sultana, 1977; Thangavelu & Ravindranath, 1985), *Metisa plana* Moore (Wood, 1971; Syed, 1978; Basri & Kevan, 1995; Kok *et al.*, 2011), *Tephemereformis* (Kaufmann, 1968), *Oiketicus kirbyi* (Mexzon, *et al.*, 2003), *Pteroma plagiophleps* (Howlader, 1990) and *Hyalarcta huebneri* (Heather, 1976).

A demographic study on the bagworm species *Pteroma pendula* population of *Acacia mangium* in Malaysia described mortality and survival rates during the life cycle stages of the bagworm species at laboratory conditions and concluded that the species had six instars and the survival rates differ in each instar according to the age of larvae and have a minimum of eight generations yearly (Cheong Loong, *et al.*, 2010).

Rhainds & Sadof (2008) studied the population dynamics of *Thyridopterix ephemeraeformis* in white pine plantations and found that localised outbreaks of bagworms are mostly persistent over time. Life cycle studies of *Eumeta crameri* was carried out in different parts of Asia, Ameen and Sultana (1977) studied the larval duration and pupation of the species, but did not mention the larval instars. Thangavelu and Ravindranath (1985) delineated nine larval instars in *Eumeta crameri* based on the morphometric analysis of larvae.

6.3. Methodology

6.3.1. General methodology: Larval bags of different species of Psychidae were collected during field visits and reared ex-situ till the emergence of adults and young ones. Life cycle studies were attempted on the hatched young larvae which were kept inside the rearing bottles containing host plants and at normal environmental conditions. Once the larvae were hatched rearing methods were modified to suit the species characteristics (host plants, dispersal behaviour). Larval growth during the rearing period was noted. The total number of larvae at the beginning of rearing and the number of larvae after time intervals, etc were noted and tabulated. The larval instars were confirmed based on the larval case renovation or modification which helps to deduce the growth of the larvae (Agrawal and Pati, 2003). In species where larvae were not hatched, the experiments could not be customized for the later stages. In cases where only adults were obtained from pupal bags, the percentage of emergence was calculated.

6.3.2. Methodology for Life cycle of *Eumeta crameri* Westwood 1854

The female pupal bags collected from the field studies were kept inside plastic containers covered with a cotton cloth tied over the lid. The time and places of the collection were noted. The emerged larvae were transferred into another container. The number of hatched larvae was noted. The larvae were transferred using a soft brush on potted *Phyllanthus emblica* plants. The number of larvae distributed on the plants were according to the plant size. From a total of 200 larvae- 100, 50 and 50 numbers of larvae

were transferred to three *Phyllanthus emblica* plants of various length. Larval dispersal, growth and distribution was observed.

The larval instars were confirmed based on the larval bag renovation or modification which helps to deduce the growth of the larvae (Agrawal and Pati, 2003). The life stages of *Eumeta crameri* were delineated based on bag renovations and a survivorship curve was plotted using the number of larvae at the time of each bag renovation.

6.3.2.1. Ballooning and dispersal study in *Eumeta crameri* Westwood 1854

The study was conducted in artificially created experimental setup conditions as discussed in the previous section. A potted *Phyllanthus emblica* plant was used for distributing the larvae. The hatched larvae were transferred artificially on the top of the plant (hitherto referred to as the mother plant), placed near the wall of a building and the distribution of larvae was observed. The plant was kept on a plinth of height 53 cm, which raised the height to a total of 153 cm from ground level. Observations on the number of larvae dispersed direction of dispersion and number of larvae remaining on the plant, were noted.

6.3.3. Methodology for Life cycle of *Metisa plana* Walker

The pupal bags of *Metisa plana* were collected by handpicking the bags attached on the walls. These bags were transferred to rearing bottles. Male and female pupal bags were sorted separately and kept in different rearing bottles (female pupal bags are larger than male bags). The bottles with pupal bags were stored under room temperature for emerging larvae. Physiological parameters like temperature and humidity were recorded at the time of rearing.

The larvae emerged from a female bag on 04/03/2020. The hatching was observed during evening. The hatched larvae were transferred in to another plastic bottle. Three saplings of *Dyopsis lutescens* (Arecaceae) were used for the rearing. This species was selected because of the higher affinity and adaptability of *Metisa plana* to this plant family (based on field observations). The larvae were then released on the plant leaf surface using a soft brush. The larvae were distributed equally on the potted plants which were arranged inside a glass container with length of 45 cm, height 25 cm and width 15 cm. The glass jar was used mainly for preventing the escape of neonates from the rearing plant by ballooning (observed during pilot studies).

The larval instars were demarcated based on the larval bag renovation or modification as it is possible to calculate the growth of the larvae corresponding to the modification of the bags (Agrawal and Pati 2003).

6.4. Results

6.4.1 *Eumeta crameri* Westwood 1854

(Plates 31, 32)

Instars of *Eumeta crameri*: The neonates of *Eumeta crameri* which emerged from the mother bag was very active and showed ballooning behaviour. The average length of the emerged larvae was 1 mm. They moved on the leaf surface with their thoracic legs and holding their abdomen upward while moving. Primary bag build commences within 1 to 2 hours of hatching by using the leaf materials from the hostplant and silk. Primary bag building was completed within one day after hatching. Larvae which failed to make bags did not survive.

The bags of the first instar larvae were cone-shaped with smooth surfaces and has two openings at the anterior and posterior ends it has a maximum length of 4 mm. The posterior end always remains closed and opens only when frass is discarded. Head and thoracic legs are protruded outside from the anterior end for feeding and moving. The opening is closed and attached to the host plant when the larvae are resting after feeding.

The duration between first instar to second instar was minimum 13 days; larvae start to modify their bags by gluing short sticks and pieces of leaves on the surface of their bag. Materials are chosen as per their bag size. The larva preferred small twigs cut down from the host plants for the bag renovation. The length range of larval bags is 5-10 mm. The larvae increase its bag size by discarding the old twigs and selecting the bigger ones in each progressive instars, from third instar a proportionally longest stick was seen in the bags of *Eumeta crameri*. It was mentioned in the work of Agrawal and Pati (1995).

The time duration between second to third instar was 15 days; it is the longest period in the cycle and the larval bag length of third instar reached to a maximum of 18 mm. The larvae took 10 days for the third renovation during the third to fourth instar after

which the larvae enter 4th instar. The minimum length of a final or fourth instar bag was 54 mm.

When the final instar larvae transformed into the pupal stage it stopped feeding and other activities. The anterior end of their bags became strongly attached on the branches of the hostplant by silk threads. No bag modifications were seen during this stage except the attachment of bag with a small thread to the substratum. Inside the bag larval head is directed towards the posterior opening. The pupation took a minimum 21 days and maximum 25 days. Three male adults emerged from the pupal bags and were active flyers. They were live up to 3-4 days (Table 15).

Based on the current observations the average lifecycle was 67.6 days duration; larval and pupal duration was 44.6 and 23.3 days respectively. *Eumeta crameri* had three larval bag renovations and four larval instars (Table 16).

Table 15: Details of successful rearing experiment with *E. crameri*

Stage/ Instar	Number of larvae	Length of bag	Days
Hatched larvae	200	-	-
Neonates- 1 st	52	0 – 4 mm	1-6
1 st - 2 nd instar	28	5 – 10 mm	13
2 nd - 3 rd instar	16	11 - 18 mm	15
3 rd - 4 th instar	09	19 – 33 mm	10
Pupa	07	33 -54 mm	21-25

Table 16: Details of successful emergence during rearing experiment with *E. crameri*

No	Date of pupation	Date of emergence	Duration of pupation	Total duration of larval life	Life span of first instar to adult	Lifespan of moth	Total life span of insect
1	06/12/2018	30/12/2018	24	42	66	4 days	70
2	08/12/2018	29/12/2018	21	44	65	3 days	68
3	12/12/2018	05/12/2019	25	48	72	4 days	76

6.4.1.1. Ballooning and dispersal in *Eumeta crameri* Westwood 1854

Ballooning and dispersal behaviour was displayed by the larvae of *E. crameri*. On release the newly hatched larvae (neonates) aggregated on the top part of the plant and showed active feeding all over the plant. The bag was built within 2 to 3 hours of hatching using silk and plant material. Dispersal from mother plant to the plants in the vicinity was accomplished by ballooning with the wind current. There was no feeding observed in ballooning larvae. The dispersal was carried mainly to the north-east direction following the direction of wind. The larvae form a single line while ballooning and move forward with the wind current. Dispersed larval bags were rediscovered after 3 days from various plants around the mother plant with the larvae actively feeding and building bags.

Out of 175 larvae hatched in natural conditions, only 34 relocated to 12 individual plants of five species. Eighteen larvae remained on the mother plant itself, where they actively fed and built bags.

6.4.2 *Metisa plana* Walker 1883

(Plates 33,34,35,36)

Neonates or early instar stage: The neonates build tiny bags around their body within one to two hours of hatching and before feeding. They build these bags from silk thread and materials collected from their mother bags or other pupal bags. After transfer to the host plant most of the larvae (90%) built tiny bags around their body. As soon as the larvae contacted the leaf surface they started feeding by scarping on the leaf. The number of larvae hatched from one mother bag or single pupal bag was in the range of 175 to 200.

The newly hatched larvae were very active and fast moving. They were 0.6 mm in length; head capsule width was 0.33mm. They mostly preferred to stay on the upper surface of the leaf or adaxial. The primary bags are very tiny and cone shaped. The average length of a primary bag was 0.85 mm and width was 0.6 mm. Some of the larvae were less active and did not show feeding and bag building activities, Bag building of newly hatched larvae was completed within maximum of 24 hours. Larvae which failed to build primary bags within this time period were weaker and they did not survive in to the next stage and died.

Instars of *Metisa plana*: Six larval instars were present in *Metisa plana*. Larval instars were counted based on the length of the larval bags and its progressive renovation. The first instar starts from the stage of construction of the bag by the larvae immediately after the emergence from the egg. The larval bags of first instar were cone shaped and smoother in appearance than later instars. Larvae shows the typical behaviour of other bagworm larvae(protrusion of their head and thoracic legs from the anterior region of the bag) and moved on the surface of leaves along with their bags in an upright position.

First instar larvae took an average of eight days to transform into the second instar. The maximum length of a first instar larval bag was 1.5 mm. The larvae began to increase their bag size by adding small leaf pieces around the anterior end of the bag. The larvae pasted two or three round and rectangular shaped leaf bits around the mouth of the bag which projected outward These leaf pieces later stick on completely to the larval bag and it gives the bag surface smoother appearance. The length of second instar larval bag was 2- 4.5 mm and the period between the instars lasted 11 days. It was the longest

period in the cycle. After the second instar, larvae modified the bag in to 3rd instar within 9 days. The bag length was 5-7.5 mm. In the 4th instar the bag was much longer and was 8-10.5 mm in length. The larval period between 3rd and 4th instars was 8 days. The fifth instar bag took a smoother appearance and was 11-12.5 mm long. An average one week was taken to complete the instar in to the last and 6th instar (Table. 17). Many larvae showed stunted growth and there was much variation in size. (Table. 18)

The pupation period of *Metisa plana* lasted a maximum of 15 days. The male pupal bag is 12.5 mm in length and 3 mm in width. At the time of pupa formation, the larvae closed both ends of the bag and attach the bag to the underside of the leaves and branches of the hostplant by a long thread. The adult moths lived up to 4-5 days after emergence. *Metisa plana* took a minimum of 37 days and maximum of 64 days between 1st to 6th instars. And the total lifespan varies between 52 to 79 days (neonate-adult). The number of larvae in each instar, time duration between each instar and larval bag length are tabulated in the Table 19.

Table 17: Bag length, duration and larval survival per instar in rearing experiment with *M. plana*

Stage/ Instar	Number of larvae	Length of bag	Days
Hatched larvae	175	-	-
1 st - 2 nd instar	146	0.85 – 1.5 mm	8days
2 nd -3 rd instar	68	2- 4.5 mm	11 days
3 rd -4 th instar	40	5- 7.5 mm	9days
4 th – 5 th instar	22	8- 10 .5 mm	8 days
5 th -6 th instar	18	11- 12.5 mm	7days
Pupa	18	12.5 mm	14-15 days

Table 18: Number of *Metisa plana* larvae with stunted growth in each instar

No	Total Number of live larvae	Number of larvae at each instar	Number of larvae with stunted growth	Number of larvae dead
1	175	0	0	0
2	146	146	0	29
3	107	68	39	39
4	92	40	52	15
5	79	22	57	13
6	62	18	44	17
7	48	18	30	14

Table 19: Duration of larval life, pupation and adult life span during rearing experiment with *Metisa plana*

No	Date of pupation	Date of emergence	Duration of pupation	Total duration of larval life	Life span of first instar to adult	Lifespan of moth	Total life span of insect
1	10/04/2020	24/04/2020	15	37	52	4 days	56
2	12/04/2020	25/04/2020	14	39	53	4 days	57
3	18/04/2020	01/05/2020	14	45	59	5 days	64
4	22/04/2020	06/05/2020	15	50	65	4 days	69
5	23/04/2022	07/05/2020	15	52	68	4 days	72
6	25/04/2020	09/05/2020	15	53	68	4days	72
7	27/04/2020	10/05/2020	14	55	69	5 days	74
8	27/04/2020	11/05/2020	15	55	70	5 days	75
9	27/04/2020	10/05/2020	14	55	69	4 days	73
10	03/05/2020	16/05/2020	14	61	75	4 days	79
11	05/05/2020	20/05/2020	15	63	78	4 days	82
12	06/05/2020	21/05/2020	15	64	79	4 days	83

6.4.3. Survivorship curve: The survivorship curve of *Eumeta crameri* and *Metisa plana* are Type III or concave type. (Fig. 51 & 52). Both species produced large numbers of offspring and the mortality of larvae increased in each progressive bag renovation. In *E. crameri* only three adult moths emerged in a generation from a brood of 200 larvae. In *Metisa plana* 13 adult moths emerged in a generation from a brood of 175 hatched larvae.

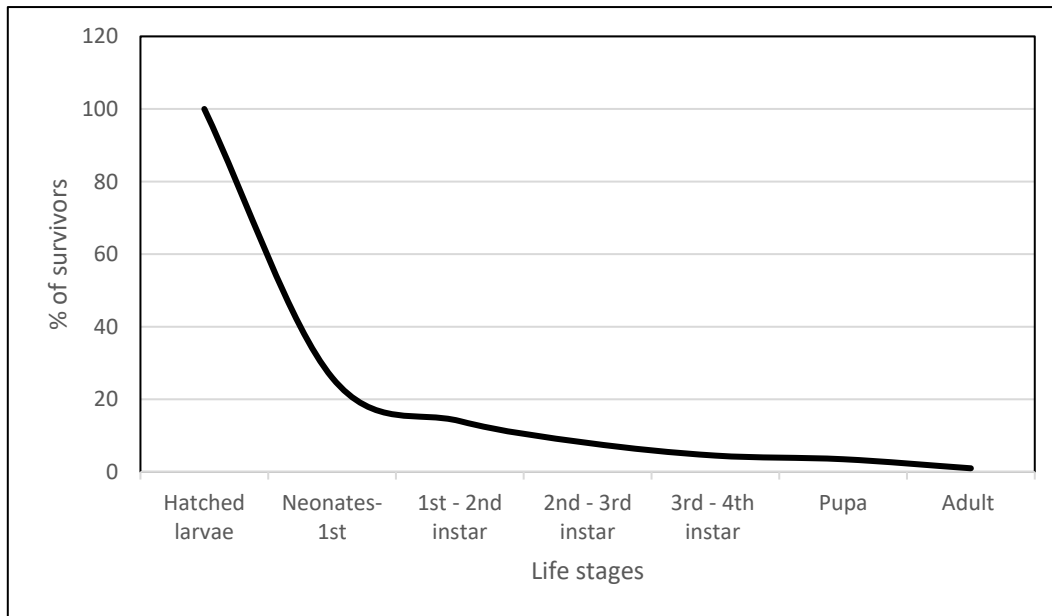


Fig 51: Survivorship curve of *E. crameri* Westwood 1854

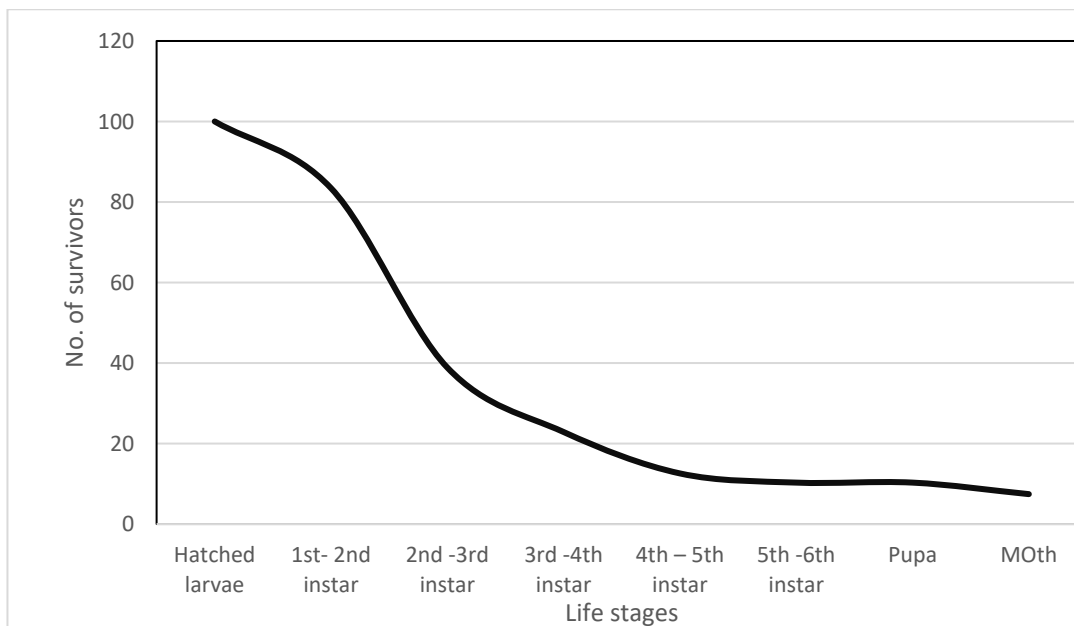


Fig 52: Survivorship curve of *M. plana* Walker 1883

6.4.4. Emergence of other species

For other species none of the female pupal bags collected and kept in the lab for rearing experiments hatched into first instar larvae as a result of which life cycle could not be studied. Of the many bags collected some of the pupal bags showed emergence. Pupae from a very small percentage of the total bags collected emerged as adults (Table 20).

Table 20: Percentage of bags showing emergence of adults out of total bags collected for each species.

Species name	Bags collected	Adults emerged	Emergence %
<i>Acanthoecia larminati</i>	23	3	13.04
<i>Acanthopsyche alstoni</i>	174	4	2.30
<i>Acanthopsyche cana</i>	23	1	4.35
<i>Acanthopsyche</i> sp.	89	2	2.25
<i>Eumeta variegata</i>	6	2	33.33
<i>Manatha albipes</i>	800	12	1.50
<i>Metisa canifrons</i>	83	1	1.20
<i>Pteroma plagiophleps</i>	650	4	0.62
<i>Clania holmesi</i> cf	43	4	9.30
<i>Eumasia thomasi</i>	64	4	6.25
<i>Eumasia venefica</i>	6	3	50.00
<i>Capulopsyche keralensis</i>	59	4	6.78
<i>Struthisca</i> cf <i>farinosa</i>	93	4	4.30
<i>Degiella</i> sp.	84	3	3.57

6.5 Discussion

An unpredictable local climate variation has been the primary source of the insect pest outbreak. This had caused a significant decrease with crops yield production (Enting & Latip,2021). In order to stop new outbreaks, it is important to understand the characteristics of these pests, particularly their life cycle. The primary abiotic element found as having a direct impact on herbivorous insects is temperature (Bale *et al.*, 2002).

Poorani *et al.* (2021) had discussed the life stages of *Manatha albipes*, an emerging pest of banana and arecanut plantations in Tamil nādu. *But* investigations on the life cycle of *M.albipes* in lab conditions was not find it successful due to the high rate of mortality in first instar larvae and attacks by predators(ants).

Life cycle studies of bagworms have been conducted worldwide, *Eumeta crameri* Westwood (Ameen & Sultana, 1977; Thangavelu & Ravindranath, 1985), *Metisa plana* Moore (Wood, 1971; Syed, 1978; Basri & Kevan, 1995; Kok *et al.*, 2011), *T.ephemereformis* (Kaufmann, 1968), *Oiketicus kirbyi* (Mexzon, *et al.*, 2003), *Pteroma plagiophleps* (Howlader, 1990), and *Hyalarcta huebneri* Westwood (Heather, 1975).

Because of the high mortality among the first instar larvae, the present study followed the method to screen the different instars based on larval bag renovation. Many studies are based on the evaluation of larval body length during each instar by dissecting the bags and measuring the larvae, but it could affect the survival of the larvae. Basri and Kevan (1995) studied *Metisa plana* and the study found six instars based on calculating the time span between the moulting of head capsules in each stage and Syed (1978) also reported six instars in *Metisa plana*. According to Wood (1971), there are four instars present in *Metisa plana*, although he did not provide any information on sample sizes, means, or ranges of head capsule widths. Basri and Kevan (1995) mentioned the complication in the measurement of bagworm larvae such as head capsule width during each instar because of its concealed nature and recommended the measurement of bag length as a better way to study the instars.

Ameen, and Sultana (1977) studied the biology and lifecycle of *Eumeta carmeri* in Bangladesh, and reported four generations per year. A detailed study on the morphology and chaetotaxy of *Eumeta carmeri* were done in Karnataka and as per their report nine larval instars are possible for *Eumeta carmeri* in a life cycle (Thangavelu and Ravindranath, 1985). The present study observed five instars in *Eumeta carmeri* based on larval bag renovation; the results correspond with the studies of Agrawal & Pati (2003) who also reported four bag renovations and five instars in *Eumeta carmeri* from Chhattisgarh.

It is hypothesized based on previous studies that the wet conditions in the study area are not optimum for the survival of bagworms and prolonged exposure to such conditions leads to the development of entomopathogenic fungi within the bag leading

to larval death. But altered climatic conditions and land use changes make it easier for insect pest species to establish and spread outside of their native ranges (Skendžić *et al.*, 2021, Hellmann *et al.*, 2008).

Life cycle studies are challenging because even though most of the species are poly phytophagous, when larvae are switched to a new plant species during development, they frequently die, proving that host preference is learned during the larval stage (Rhainds *et al.*, 2009). But the very first steps toward effective bagworm control would be to identify and comprehend the fundamental facts about the biology of the bagworm, such as its behaviour, structure and life cycle which could be slightly different in each region based on the regions climatic and floral peculiarities.

6.6 Conclusion

The life cycle study of bagworms posed many challenges like high mortality in younger stages, stunted growth, unfavourable conditions. Watt and Mann (1903) mentioned the difficulty with experiments in breeding cages with very few or no adults being obtained. Rearing of potential insect pests like bagworms needs controlled breeding conditions to prevent the outbreak in the nearest places. It is recommended that the preliminary data on the life span of two species in the study area and emergence percentage of other species should be treated as a baseline and need further studies to understand the life cycle of bagworm species in the region be conducted.

PLATE 31

Life cycle of *Eumeta crameri* –Life stages

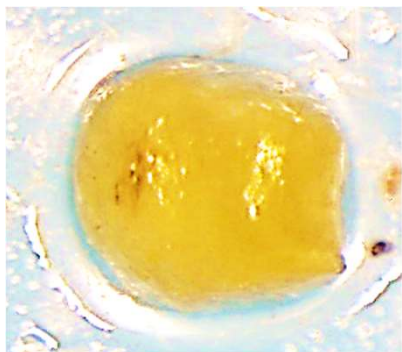


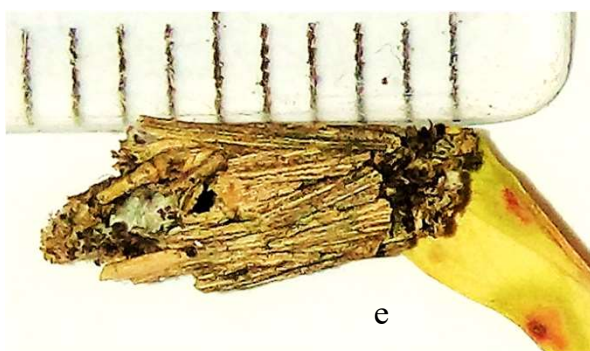
Figure a: Egg of *Eumeta crameri*



Figure b: Neonate larva of *Eumeta crameri*



Figures c & d: First instar larval bags of *Eumeta crameri*



Figures e,f: Second instar larval bags of *Eumeta crameri*

PLATE 32

Life cycle of *Eumeta crameri* –Life stages



Figure a: 4th instar of *Eumeta crameri*



Figure b: Second instar bag under renovation



d

Figures c & d: Pupal bags of *Eumeta crameri*



Figure e: Adult moth

PLATE 33

Life cycle of *Metisa plana* - -Rearing set



Figures: a. Sorting and transferring of larvae to hostplant, b,c & d. Feeding damage on the leaves of *Dypsis lutescens* by first instar larvae of *Metisa plana*

PLATE 34

Life cycle studies of *Metisa plana* - Life stages



Figure a: First instar larva

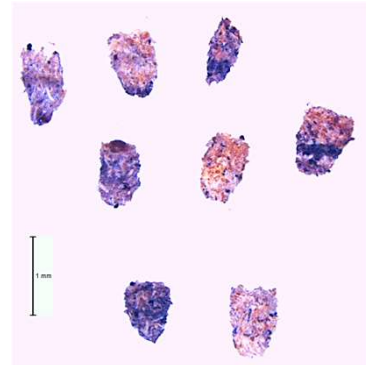


Figure b: First instar larval bags



Figure c: First instar larval bag and larva

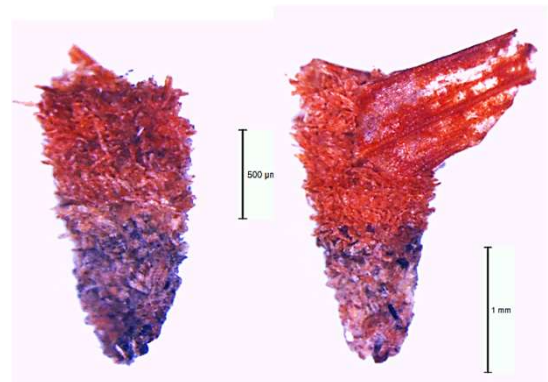


Figure d: First instar larval bags under renovation

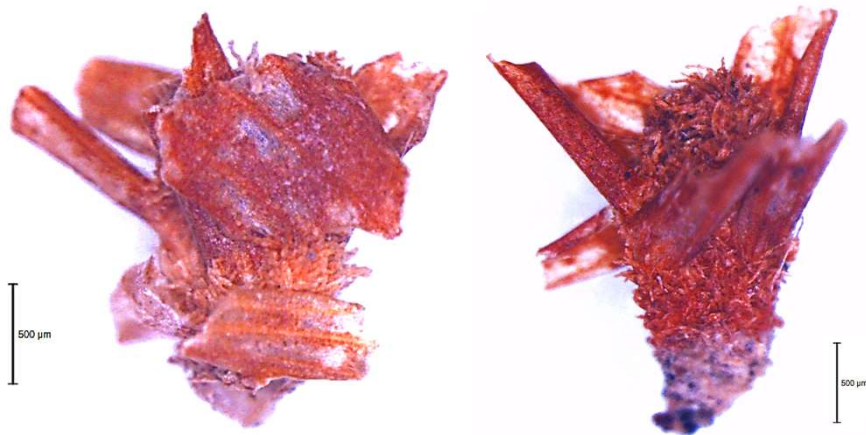


Figure e: Second instar larval bags

PLATE 35

Life cycle studies of *Metisa plana* - Life stages



Figure a: Third instar larval bag



Figure b: Fourth instar larval bag

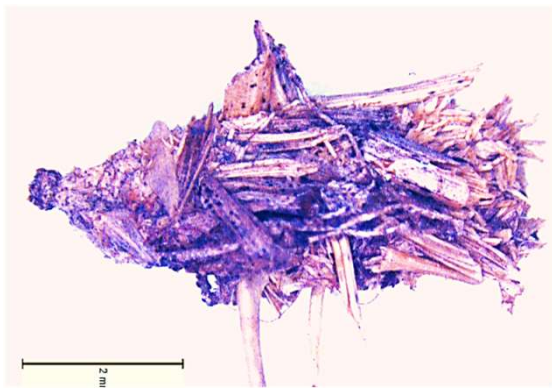


Figure c: 4th instar larval bag



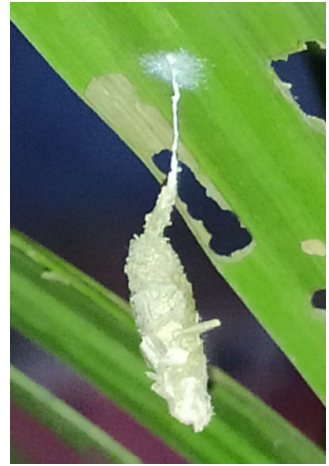
Figure d: 5th instar larval bag



Figure e, f: 6th instar larval bag

PLATE 36

Life cycle studies of *Metisa plana* - Life stages



Figures a,b,c: Pupal bags of *Metisa plana*



Figure d: Pupal bag with pupal exuvia



Figure e: Adult moth

CHAPTER 7

Recommendations

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Recommendations

7. Recommendations

In the context of the present study the following recommendations are put forward:

7.1. For academic purposes

- The present study has not covered forest lands and monoculture plantations. It is recommended that extensive surveys in these habitats be conducted to get a comprehensive idea of the species diversity and distribution of Psychids in Kerala.
- The present study has showcased the potential of Psychidae to throw up species new to science. Extensive field surveys and detailed taxonomical studies with molecular characterization are recommended to expand the checklist of Psychidae species in Kerala.
- It is recommended that consistent monitoring of the life cycle and life history traits of all the economically important bagworm species be done for a better understanding of their biology and pestilence potential across different habitats and climatic conditions.
- Proper control measures should be developed for established pest species in the area.

7.2. For policymakers and agriculturists

- Threat analysis for identified pest species done in this study could be done for unidentified species and should be updated with changes in land use.
- Host plants with no economic significance but which act as a reservoir habitat for these moths should be identified and a repository should be made.
- Such plants should not be planted in monocultures or in long stretches in highway greening projects to prevent the spread of these poly phytophagous insects.
- Farmers should be enabled to identify cases of Psychidae to prevent pestilence in crops.

- A network of experts with countries such as Malaysia, Indonesia and Japan where Psychidae have been major pests must be initiated for the exchange of information.

SUMMARY

SUMMARY

- Family Psychidae are commonly called bagworms, bagworm moths, or bag moths because of their bag-making behavior
- The Fauna of British India by Hampson (1892) is considered the most comprehensive work in Psychidae to date.
- Field survey and collection was done in human-inhabited areas in all districts of Kerala. These areas included roadsides, gardens, household areas, parks, private properties, plantations, and agricultural fields.
- The COI Sequencing and Phylogeny analysis using MEGA 11 following Tamura *et al.*, 2021 was used for the confirmation of subfamily, especially for unidentified species.
- The present study documented 26 different species belonging to six subfamilies of bagworms from the study area, Kerala of which 14 species were identified up to the species level, three up to the genus level and nine species are unidentified.
- The list includes the reports of one new genus and three new species and one species rediscovery and neotype designation from Kerala, India. It also includes five new reports from Kerala.
- Subfamily Oiketicinae was the most dominant group with eighteen species belonging to seven genera, *Acanthoecia*, *Acanthopsyche*, *Eumeta*, *Manatha*, and one undefined taxon.
- *Acanthopsyche alstoni*, which was previously known only from its larval bags, was redescribed after 119 years from India, and designated as a neotype.
- Subfamily Metisinae had two genera, *Metisa* and *Pteroma*, and three species, *M.canifrons* (first report from Kerala), *M. plana*, and *P. plagiophleps*.
- Subfamily Eumasiinae and Typhoniinae had three species each. Three species including two new species, *Eumasia thomasi*, *Eumasia venefica* and one unidentified species were recorded from subfamily Eumasiinae.
- Subfamily Taleporiinae had one new genus described, *Capulopsyche* Usha *et al.*, 2023. and species *Capulopsyche keralensis*. Usha *et al.*, 2023.
- COI sequences of 13 species were uploaded in NCBI GenBank

- Based on the major morphological characteristics of the species taxonomic key for the 10 identified genera of Psychidae moths from the study area was prepared.
- Detailed descriptions of the bags of all the species of the study area were made along with photographs and detailed diagrams. Identification keys of all the identified species bags was made
- Seventy-three hostplant species belonging to thirty-eight families were found infested by nine bagworm species from the study area. Some species are showing voracious feeding on plants while others depend on the plants only for their pupal bag attachment
- Distribution mapping of all the identified species was done using the open-source software QGIS.
- Threat analysis of bagworm species which caused damage to host plants was done by overlaying their distribution area with the areas of mixed crops and other monoculture plantations as shown in the CESS land use atlas. The area of distribution of each economically important plant is bananas (528.99 km²), areca nut (957.39 km²), oil palm (4.128 km²), Teak (853.6 km²), Eucalyptus (189.5 km²), Coffee (45.33 km²). In addition to economically important crops, the bagworm species were also present on other host plants present in the vicinity of agricultural fields or plantations.
- *Phyllanthus emblica* and *Lagerstroemia speciosa* were most affected by bagworm infestations.
- *Eumeta crameri*, followed by *Manatha albipes*, *Acanthopsyche alstoni* and *Metisa canifrons* indicated that these species infested a maximum number of plant species and individuals thus sealing their pest status.
- One dipteran parasitoid (*Nealsomyia rufipes*) and eighteen hymenopterans including 17 parasitoids and one predator were recorded. These have the potential to be used as biocontrol agents.
- Life cycle studies of the species *Eumeta crameri* and *Metisa plana* was done using the hatched young larvae.
- *Eumeta crameri* had 4 instars. Based on the current observations the average lifecycle of *Eumeta crameri* was 67.6 days in duration. The larval and pupal duration of *Eumeta crameri* was 44.6 and 23.3 days respectively. *Metisa plana*

had 6 instars in the study. *Metisa plana* took a minimum of 37 days and a maximum of 64 days between the 1st to 6th instars. The total lifespan varies between 52 to 79 days (neonate-adult).

- The percentage of emergence from pupal bags was calculated for species other than *Eumeta crameri* and *Metisa plana*.
- Intensive and extensive surveys and monitoring are recommended.

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APPENDICES

APPENDIX A: Reports of Psychidae from Kerala from the previous studies

Sl.No.	Articles published based on the studies of moths in Kerala	Region of the study	Psychidae Species mentioned in the study
1.	Alex <i>et al.</i> , 2021	Kavvai River Basin	3, <i>Eumeta crameri</i> , <i>Eumeta variegata</i> , <i>Eumeta sps</i>
2.	George Mathew, 1994	Silent Valley National Park	0
3.	Katewa and Pathania, 2019	Western Ghats	1, <i>Clania crameri</i>
4.	Mathew and Nair, 1983	Kerala	<i>Pteroma plagiophleps</i>
5.	Mathew and Nair, 1986	Kerala	<i>Pteroma plagiophleps</i>
6.	Mathew and Rahamathulla, 1995	Silent Valley National Park	0
7.	Mathew <i>et al.</i> , 2004	Peppara Wildlife Sanctuary	0
8.	Mathew <i>et al.</i> , 2004	Shendurny Wildlife Sanctuary	0
9.	Mathew <i>et al.</i> , 2005	Peechi-Vazhani Wildlife Sanctuary	05, <i>Metisa plana</i> , <i>Eumeta crameri</i> , <i>Brachycyttarus Sp.</i> , <i>Pteroma plagiophleps</i> , <i>Thyridopteryx sp.</i>
10.	Mathew <i>et al.</i> , 2018	Vagamon Hills	0
11.	Mathew <i>et al.</i> 2007	Neyyar Wildlife Sanctuary	0
12.	Mathew, 2010	KFRI report Kerala	4, <i>Metisa plana</i> , <i>Pteroma plagiophlep</i> , <i>Eumeta crameri</i> , <i>Brachycyttarus subteralbata</i>
13.	Nair and Mathew, 1992	Kerala	<i>Pteroma plagiophelps</i>
14.	Nair, 1981	Kerala	<i>Pteroma plagiophleps</i> Hamp
15.	Sondhi <i>et al.</i> , 2021	Shendurney and Ponmudi in Agastyamalai Biosphere Reserve	0
16.	Sondhi <i>et al.</i> , 2018	Shendureney	0

Sl.No.	Articles published based on the studies of moths in Kerala	Region of the study	Psychidae Species mentioned in the study
17.	Swafvan and Joshi, 2020	Coffee plantations in Northern Kerala	0
18.	Swafvan <i>et al.</i> , 2020	Agroecosystems of Northern Kerala	0
19.	Therratil, 2013	Chettuva mangroves	<i>Pteroma plagiophleps</i>
20.	Valappil, 2020	Kerala	01, <i>Eumeta variegata</i>
21.	Varma <i>et al.</i> , 1989	Kerala	<i>Pteroma plagiophleps</i>
22.	Varma, 2007	Kerala	<i>Brachycyttarus subteralbatus</i>
23.	Yamini & John, 2011	Kakkani region near Dhoni Forest	0

APPENDIX B(a): Details of sites visited in the study areas

Sl.no	District	Name of places visited	Latitude	Longitude
	Thrissur	Wadakkanchery	10.3942° N	76.1410° E
		Pullanikkad	10.6617° N	76.2363° E
		Vazhani dam	10.6412° N	76.3084° E
		Akamala	10.6798° N	76.2671° E
		Enkakkad	10.6599° N	76.2566° E
		Ponnukara	10.4743° N	76.2856° E
		Cheruthuruthi	10.7395° N	76.2760° E
		Kerala Varma College	10.5300° N	76.1952° E
		Nellikunnu	10.5208° N	76.2261° E
		Mundupalam	10.5118° N	76.2210° E
		Chelakkara	10.6941° N	76.3464° E
		Athani	10.3756° N	76.1252° E
		Ottupara	10.6645° N	76.2515° E
		Pazhayannur	10.6824° N	76.4230° E
		Edakkazhiyur	10.6187° N,	75.9930° E
		Thalikkulam	10.4312° N	76.0773° E
		Bishop house Thrissur	10.5265° N	76.2269° E
		Nadathara	10.5052° N	76.2696° E
		Erinjeri angadi	10.3115° N	76.135°E
		Erattakulangara	10.6628° N	76.2366° E
		Latin church Thrissur	10.5180° N	76.2184° E
		North bus stand	10.5302° N	76.2147E
		Vadakkechira	10.3147° N	76.1256° E
		Kannothpadam	10.5166° N	76.2165° E
		Vazhalikkavu	10.7432° N	76.3294° E

	Kuranchery	10.6319° N	76.2275° E
	Kalathode	10.5276° N	76.2419° E
	Poomala	10.6010° N	76.2423° E
	Pachavadi beach	10.6202° N	75.9856° E
	Vilangankunnu	10.5571°N	76.1690° E
	Pukunnam	10.3227° N	76.1200° E
	Panamukku	10.2926° N	76.1282° E
	Nedupuzha	10.4867° N	76.1929° E
	Pullu	10.4575° N	76.1523° E
	Kanimangalam	10.2998° N	76.1231° E
	Cheroor	10.3248° N	76.1415° E
	Ammadam	10.4538° N	76.1929° E
	Cherpu	10.4324° N	76.2045° E
	Vallachira	10.4420°N	76.2184° E
	Poochinipadam	10.4420° N	76.2183° E
	Kuttanellur	10.5081° N	76.2515° E
	Ollur	10.4825° N	76.2387° E
	Patturaikkal	10.5335° N	76.2128° E
	Viyyur	10.5523° N	76.2175° E
	Irinjalakkuda	10.3559° N	76.2126° E
	Chettuva	10.3127° N	76.2524° E
	East fort	10.3120° N	76.1325° E
	Palace road	10.5260° N	76.2170° E
	Polukkara	10.5319° N	76.2523° E
	Chimminy dam	10.4389° N	76.4615° E
	Pathazhakundu dam	10.6186° N	76.2399° E

		Christ College	10.2128° N	76.1245° E
		Chembukkavu	10.3149° N	76.1313° E
		Koorkanchery	10.5053° N	76.2105° E
		Chavakkad	10.3459° N	76.1797° E
		Mapranam	10.2354° N	76.1486° E
		General hospital road	10.5241° N	76.2169° E
		Nedumbassery	10.1679° N	76.3978° E
		Athani	10.9142° N	76.2118° E
		Angamali	10.1135° N	76.2312° E
		Thuruthissery	10.9142° N	76.2118° E
		Aluva	10.1004°N	76.3570° E
		Thripunithura	9.9526° N	76.3639° E
		Chowara	10.1283° N	76.3732° E
		CUSAT campus	10.0443° N	76.3282° E
		Vypin	9.9740° N,	76.2440° E
		Muvattupuzha	9.9894° N,	76.5790° E
		Iringole kavu	10.0630° N	76.3003° E
		Perumbavoor	10.1146° N	76.4778° E
		Fortkochi	9.9658° N	76.2421° E
		Edappally	10.0261°N	76.3125° E
		Ezhattumugam	10.2952° N	76.4524° E
		Poikattussery	10.1637° N	76.3461° E
		Paniyeli poru	10.1738° N	76.6008° E
		Malayattoor	10.1955° N	76.4968° E
		Subash Bose park	9.9715° N	76.2794° E
	Palakkad	Nenmara	10.5934° N	76.6006° E

		Kollengode	10.6139° N	76.6908° E
		Pothundi dam	10.5418° N	76.6254° E
		Nelliyampathy	10.5354° N	76.6936° E
		Kinassery	10.7288° N	76.6658° E
		Padagiri	10.4793° N	76.7014° E
		Palakkad fort	10.7637° N	76.6571° E
		Kanalpalam	10.7256° N	76.6742° E
		Kodumbu	10.7560° N	76.6769° E
		Malampuzha	10.4950° N	76.4117° E
		Ambalappara	10.8318° N	76.4071° E
		Parali	10.4751° N	76.3345° E
		Kallepully	10.7898° N	76.6745° E
		Ottapalam	10.7767° N	76.3759° E
		Manissery	10.7711° N	76.3374° E
	Malappuram	University of Calicut	11.2587° N	75.7803° E
		Tirur	10.9167° N	75.9245° E
		Perinthalmanna	10.9760° N	76.2254° E
		Valanchery	10.8878° N	76.0732° E
		Edappal	10.7837° N	76.0076° E
		Kakkanchery	11.1557° N	75.8912° E
		Anakkayam	11.0835° N	76.1175° E
		Kottakkal	10.9990° N	75.9918° E
	Kozhikode	Kozhikode beach	11.1545° N	75.4623° E
		Kallai	11.2352° N	75.7938° E
		Kozhikode	11.2588° N	75.7804° E
		Malabar Christian College	11.2641° N	75.7785° E

		Zamorin's Guruvayurappan College	11.2411° N	75.822° E
		Mutheri	11.3423° N	75.9773° E
		Kannothu	11.4751° N	75.9901° E
		Mukkom	11.3215° N	75.9354° E
		Mathara	11.1439° N	75.5042° E
	Idukki	Munnar	10.0889° N	77.0595° E
		Kattapana	9.7557° N	77.1154° E
		Nariyampara	9.7424° N	77.0939° E
		Vattavada	10.1777° N	77.2538° E
		Idukki township	9.8584° N	76.9528° E
		Anchuruli	9.7713° N	77.0747° E
		Thommankuth waterfall	9.9592° N	76.8190° E
		Adimali	10.0115° N	76.9528° E
	Alappuzha	Alappuzha beach	9.4927° N	76.3178° E
		Ambalapuzha	9.3787° N	76.3628° E
		Cherthala	9.6741° N	76.3401° E
		Kayamkulam	9.1748° N	76.5013° E
		Thottappilly	9.3222° N	76.3840° E
	Kollam	Chadayamangalam,	8.5157° N	76.5202° E
		Jadayurock garden	8.8731° N	76.8694° E
		Kollam	8.8932° N	76.6141° E
		Kollam beach	8.5232° N	76.3520° E
		Paravur	8.8142° N	76.6673° E
	Pathanamthitta	Adavi	9.2644° N	76.9355° E
		Ranni	9.3866° N	76.7856° E
		Vallicode	9.2233° N	76.7769° E
		Kozhenchery	9.3346° N	76.7077° E
		Thiruvalla	9.3853° N	76.5750° E

		Konni	9.2267° N	76.8497° E
	Kottayam	Pala	9.7131° N	76.6833° E
		Kanjikuzhi	9.5873° N	76.5431° E
		Thellakom	9.6448° N	76.5474° E
		Kottayam town	9.5916° N	76.5222° E
		Ettumanoor	9.6706° N	76.5579° E
		Chingavanam	9.5248° N	76.5247° E
		Aruvikuzhi waterfall	9.3610° N	76.4001° E
	Wayanad	Sultan Bathery	11.6629° N	76.2570° E
		Ambalavayal	11.6197° N	76.2103° E
		Malavayal	11.6337° N	76.2552° E
		Poomala	11.6458° N	76.2503° E
		Nenmeni	11.6313° N	76.2769° E
		Beenachi,	11.6620° N	76.2340° E
		Edakkal,	11.6268° N	76.2343° E
		Kambalakkad	11.5516° N	76.0402° E
		Kattikulam	11.8467° N	76.0631° E
		Karlada lake garden	11.3902° N	75.5854° E
		Banasurasagar dam	11.6700° N	75.9578° E
		Kuruvadweep	11.8217° N	76.0922° E
		Thirunelly	11.9081° N	75.9971° E
		Soochipara waterfall	11.3044° N	76.947° E
		Naiketty	11.6653° N	76.3144° E
	Kannur	Pariyaram,	12.1197° N	75.3189° E
		Thalassery	11.7491° N	75.4890° E
		Parasinikkadavu,	11.9843° N	75.3995° E
		Snake Park	11.59'24° N	75.2321° E
		Brennan College	11.7780° N	75.4694° E
		Dharmadom	11.7775° N	75.4703° E
		Payyanur	12.5290° N	75.1144° E
		Muzhuppilangad beach	11.7932° N,	75.4441° E
		Chal beach	11.9233° N	75.3126° E
	Kasaragod	CPCRI, Chowki	12.5279° N	74.9685° E
	Thiruvananthapuram	Varkala	8.4412° N	76.4224° E

		Priyadarsini planetarium	8.5100° N	76.9465° E
		Melarannur	8.2919° N	76.5759° E
		Zoo Trivandrum	8.5106° N	76.9549° E
		Karyavattom	8.5678° N	76.8908° E
		Vellayani	8.4453° N	76.9925° E

APPENDIX B(b): Details of bagworms and hostplants from different sites visited in the study areas

Subfamily	Species name	Author and description year	Collected adult specimens	Larval/pupal bags collected	Hostplants
Oiketicinae	<i>Acanthoecia larminati</i>	Heylaerts, 1904	03	23	Nil
	<i>Acanthopsyche alstoni</i>	Watt & Mann, 1903	04	174	<i>Coffea arabica</i> , <i>Datura arborea</i> , <i>Thuja occidentalis</i> , <i>Lagerstroemia speciosa</i> , <i>Madhuca nerifolia</i> , <i>Dracaena trifasciata</i> , <i>Tradescantia spathacea</i> , <i>Dracaena reflexa</i> , <i>Grevillea robusta</i> , <i>Araucaria heterophylla</i> , <i>Ficus benamina</i> , <i>Epipremnum aureum</i>
	<i>Acanthopsyche cana</i>	Hamson, 1892	01	23	<i>Phyllanthus reticulatus</i> Poir, <i>Phyllanthus myrtifolius</i> , <i>Mikania micrantha</i> Kunth,
	<i>Acanthopsyche</i> sp.	Hamson, 1892	02	89	<i>Hydrangea macrophylla</i> , <i>Piper nigrum</i> , <i>Ixora coccinea</i> , <i>Trema orientalis</i> , <i>Garcinia gummi-gutta</i>
	<i>Eumeta crameri</i>	Westwood, 1854	18	423	<i>Phyllanthus emblica</i> , <i>Casuarina equisetifolia</i> , <i>Terminalia catappa</i> , <i>Tamarindus indica</i> , <i>Psidium guajava</i> , <i>Mangifera indica</i> , <i>Mikania micrantha kunth</i> , <i>Lawsonia inermis</i> , <i>Hyptis suaveolens</i> , <i>Lagerstroemia speciosa</i> , <i>Sida acuta</i> , <i>Tectona grandis</i> , <i>Urena sinuate</i> , <i>Phyllanthus myrtifolium</i> , <i>Butea monosperma</i> , <i>Caesalpinia coriaria</i> , <i>Ipomoea marginata</i> , <i>Chromolaena odorata</i> , <i>Syzygium cumini</i> , <i>Theobroma cacao</i> , <i>Melaleuca leucadendra</i> , <i>Trema orientalis</i> , <i>Mimosa pudica</i> , <i>Crotalaria pallida</i> , <i>Phyllanthus reticulatus</i>

Subfamily	Species name	Author and description year	Collected adult specimens	Larval/pupal bags collected	Hostplants
					<i>Poir, Cleome viscosa L., Acacia auriculiformis</i>
	<i>Eumeta variegata</i>	Snellen, 1879	02	06	<i>Phyllanthus emblica, Casuarina equisetifolia</i>
	<i>Manatha albipes</i>	Moore, 1877	12	800	<i>Terminalia catappa, Dyspis lutescens, Pongamia pinnata, Phyllanthus emblica, Cassia fistula, Syzygium samarangense, Heliconia rostrata, Tamarindus indica, Lagerstroemia speciosa, Casuarina equisetifolia, Terminalia cuneata, Terminalia panniculata, Cocos nucifera, Elaeis guineensis, Roystonea regia, Syzygium cumini, Butea monosperma, Ixora coccinea, Tectona grandis, Calliandra haematocephala, Hibiscus rosa-sinensis, Jasminum sambac, Psidium guajava, Avicennia officinalis, Magnolia champaca, Billbergia pyramidalis, Musa paradisiacal</i>
	<i>Clania holmesi incertae sedis</i>	Watt, 1898	04	43	<i>Lawsonia inermis, Phyllanthus emblica, Casuarina equisetifolia, Terminalia cuneata, Lagerstroemia speciosa, Allamanda cathartica, Polyalthia longifolia, Cardiospermum halicacabum, Ficus benamina</i>
	Unidentified sp.1	-	Nil	28	<i>Cocos nucifera, Casuarina equisetifolia, Terminalia catappa</i>
	Unidentified sp.2	-	Nil	12	<i>Ixora coccinea,</i>
	Unidentified sp.3	-	Nil	09	<i>Nil</i>

Subfamily	Species name	Author and description year	Collected adult specimens	Larval/pupal bags collected	Hostplants
	Unidentified sp.4	-	Nil	04	<i>Terminalia catappa</i>
	Unidentified sp.5	-	Nil	02	<i>Nil</i>
	Unidentified sp.6	-	Nil	07	<i>Cocos nucifera</i>
	Unidentified sp.7	-	Nil	04	<i>Lagerstroemia speciosa</i>
Metisinae	<i>Metisa plana</i>	Walker, 1883	21	310	<i>Casuarina equisetifolia</i> , <i>Mangifera indica</i> , <i>Heliconia rostrata</i> , <i>Cyrtostachys renda</i> , <i>Borassus flabellifer</i>
	<i>Metisa canifrons</i>	Hampson, 1910	01	83	<i>Terminalia catappa</i> , <i>Phyllanthus emblica</i> , <i>Dyopsis lutescens</i> , <i>Caesalpinia coriaria</i> , <i>Magnolia champaca</i> , <i>Chrysophyllum caimito</i> , <i>Mangifera indica</i> , <i>Tecoma stans</i> , <i>Heliconia rostrata</i> , <i>Acacia auriculiformis</i> , <i>Pongamia pinnata</i> , <i>Piper nigrum</i> , <i>Gmelina arborea</i> , <i>Cyrtostachys renda</i> , <i>Terminalia cuneata</i>
	<i>Pteroma plagiophleps</i>	Hampson, 1892	04	650	<i>Terminalia catappa</i> , <i>Delonix regia</i> , <i>Phyllanthus emblica</i> , <i>Ixora coccinea</i> , <i>Psidium guajava</i> , <i>Annona muricata</i> , <i>Epipremnum aureum</i> , <i>Lagerstroemia speciosa</i> , <i>Theobroma cacao</i> , <i>Tamarindus indica</i> , <i>Terminalia neotaliala</i>
Typhoniinae	<i>Degiella</i> sp.nov	Sobczyk, 2009	03	84	<i>Nil</i>
	<i>Struthisca</i> cf <i>farinosa</i>	Meyrick, 1919	04	93	<i>Nil</i>
	Unidentified sp. 8	-	Nil	05	<i>Nil</i>

Subfamily	Species name	Author and description year	Collected adult specimens	Larval/pupal bags collected	Hostplants
Eumasiinae	<i>Eumasia thomasi</i>	Usha <i>et al.</i> , 2022	04	64	<i>Nil</i>
	<i>Eumasia venefica</i>	Usha <i>et al.</i> , 2023	03	06	<i>Nil</i>
	<i>Eumasia sp.</i>	Chrétien, 1904	Nil	03	<i>Nil</i>
Taleporina	<i>Capulopsycha keralensis</i>	Usha <i>et al.</i> , 2023	04	59	<i>Coffea arabica</i>
Unknown	Unidentified sp. 9	-	Nil	02	<i>Nil</i>

Eumasia venefica sp. nov. a new species of the subfamily Eumasiinae (Lepidoptera: Psychidae) from India with atypical larval ecology

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Abstract

A new species of bagworm moth, *Eumasia venefica* sp. nov., from the subfamily Eumasiinae, is described from Kerala, India. This species has a peculiar larval ecology, larval case structure and an association with lichens. The paper describes the detailed taxonomy of the adult and the larval stages of the species.

Key words: Bagworm, Psychidae, Eumasiinae, Kerala, lichens

Introduction

Subfamily Eumasiinae comes under the lepidopteran family Psychidae, which consists of 241 genera and 1450 species worldwide (Sobczyk 2011, 2019; Van Nieukerken *et al.* 2011). This subfamily was defined by Arnscheid & Weidlich (2017) based on the monotypic genus *Eumasia* Chrétien, 1904. Fifteen species have been described in this subfamily worldwide (Sobczyk 2011, 2015; Arnscheid & Weidlich 2017; Roh *et al.* 2018) including a recently reported species *Eumasia thomasi* from India (Usha *et al.* 2022b). Only two species (*Eumasia arenatella* (Walker, 1864): Sri Lanka, India and *Eumasia exoria* Meyrick, 1919: Pusa, Bengal, India) has been described from India (Sobczyk 2011) before *E. thomasi*.

Case-making behaviour using different materials is a significant characteristic of bagworms (Rhainds *et al.* 2009). Many species use lichens as a building and decoration material for their larval and pupal cases. Frequent lichen interactions have been reported in many subfamilies of Psychidae.

During our field visits to Nariyamapara in Idukki district of Kerala, India, several larval cases of peculiar shape were found on lichen covered rocks. The larval and pupal cases were collected from the location and reared in the laboratory till adult emergence. Adult females and males hatched from the pupal cases.

Characteristic features of Eumasiinae were evident in the adult moths, such as well-developed wings in both sexes, filiform antennae with each segment of male antennae covered with short cilia and middle segment with dorsally fanned scales, narrow lanceolate forewing with seven veins from the dc, blunt sacculus, and absence of annellus and juxta in the male genitalia (Saigusa & Sugimoto 2005; Arnscheid & Weidlich 2017; Roh *et al.* 2018).

Further examination of adult morphology, genitalia, larval case structure and larval ecology confirmed that it is a hitherto undescribed species. The paper describes the detailed taxonomy of adults, larval behaviour and phylogenetic positioning based on the COI sequence of the species.

Materials and methods

Thirteen larval and pupal cases were collected from Nariyamapara, Idukki district of Kerala. The collected cases

were reared in rearing bottles in the laboratory at room temperature. The activity of larvae and pupae was observed frequently. Four adults, two males and two females emerged from the pupal cases. The morphological characteristics of both sexes were studied and described. Detailed description of wing patterns, colouration, wing venation and genital structure was made. The larval and pupal behaviour during the rearing was noted and described. Photographs and measurements of the specimens were taken using a Leica S8APO stereomicroscope.

COI Gene Sequencing: DNA was extracted from the larva. Sequencing of the cytochrome oxidase I gene of the species was done at the Rajiv Gandhi Centre for Biotechnology (RGCB), Trivandrum, using the forward and reverse primers LCO and HCO respectively (Folmer *et al.* 1994). Forward and reverse reads were assembled following Drummond *et al.* (2010). The evolutionary history was inferred by using the Maximum Likelihood method and General Time Reversible model (Nei & Kumar 2000). Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pairwise distances estimated using the Maximum Composite Likelihood (MCL) approach and then selecting the topology with superior log likelihood value. The tree is drawn to scale, with branch lengths measured in the number of substitutions per site (next to the branches). This analysis involved nine nucleotide sequences of which eight were retrieved from the NCBI database (Table 1). Codon positions included were 1st+2nd+3rd+Noncoding. There was a total of 687 positions in the final dataset. Evolutionary analyses were conducted in MEGA11 (Tamura *et al.* 2021). One outgroup taxon (*Manatha albipes* Moore, 1877) from the psychid subfamily Oiketicinae was included.

TABLE 1. Details of COI sequences used for phylogenetic analysis.

SI No	Accession number	Species	Country	Authors	Base pair length
1	JN299400	<i>Eumasia parietariella</i>	Slovenia	Unpublished	658
2	JN307737	<i>Eumasia parietariella</i>	Spain	Unpublished	658
3	LC094211	<i>Eumasia muscella</i>	Japan	Sugawara,H. and	665
4	LC094205	<i>Eumasia muscella</i>	Japan	Hayashi,F. 2015	662
5	LC094199	<i>Eumasia viridilichenella</i>	Japan	Unpublished	665
6	LC094198	<i>Eumasia viridilichenella</i>	Japan		665
7	OP302728	<i>Eumasia thomasii</i>	India	Usha <i>et al.</i> 2022 b	687
8	OR044899	<i>Eumasia venefica</i> sp. nov.	India	This study	655
9	MN717272	<i>Manatha albipes</i>	India	Usha <i>et al.</i> 2022 a	692

The holotype and paratypes will be deposited at the Zoological Survey of India Museum, Calicut, Kerala after evaluation and open defence of the Ph.D. thesis of the first author and is currently kept at the Zoology department at St. Thomas College, Thrissur.

Abbreviations

RGCB	Rajiv Gandhi Centre for Biotechnology, Trivandrum
NCBI	National Centre for Biotechnology Information, Bethesda, Maryland, USA
BLAST	Basic Local Alignment Search Tool
EI	Eye-Index (Smallest eye distance / vertical eye diameter in anterior view)
WI	Forewing-Index (maximum length base to apex divided by the maximum width)
mASL	meters Above Sea Level

Observations and results

Taxonomic part

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1829

Subfamily Eumasiinae Arnscheid & Weidlich, 2017

Genus *Eumasia* Chrétien, 1904

Eumasia Chrétien, 1904: 120. Type species: *Coleophora parietariella* Heydenreich, 1851

***Eumasia venefica* sp. nov.**

(Figs: 1–11)

Type material. Holotype. ♂, INDIA, Kerala, Nariyampara, Kattappana, Idukki, 9.7424° N, 77.0939° E, 28-x-2022, with larval case, leg. Usha A U.

Paratypes: one female (with larval case), same data as holotype, 19-x-2022, 3 larval cases without pupal exuviae, leg. Usha A U.

Etymology. Larval bags have a ‘witches’ hat’ appearance, a disc-like anterior and a tubular posterior part. The Latin word ‘*veneficus*’ means wizard. As *Eumasia* is a female term the feminine form of ‘*veneficus*’, ‘*venefica*’, has been used. Hence the name *Eumasia venefica*.

Description. Holotype ♂ (Fig. 1), Wingspan 8.0–8.2 mm, body length 3.0–3.2 mm, forewing length 3.8 mm including fringes, forewing width 1.1 mm, WI 3.4 mm, hindwing length 3.3 mm.

Head. Vertex densely covered with pale golden coloured hairs; the frons has a bilobed tuft of golden hairs. eyes are large, EI 0.76 mm. Antenna thread-like, short cilia on segments, 26 segmented, 1.6 mm long.



FIGURE 1. Holotype of *Eumasia venefica* sp. nov.



FIGURE 2. Paratype of *Eumasia venefica* sp. nov.

Thorax. Covered densely with light brownish scales. Forewings are covered with pale brown and blackish scales. The scales are broad and have 5 pointed apices. Ground colour of the forewing is pale brown and the blackish scales in the forewing form patches and are randomly distributed on the wing surface (Fig. 3). Hindwings are whitish without any spots or patterns and covered with pale golden scales. Wings are lanceolate, apex pointed, outer margin with long brownish fringe hairs. Legs are covered with long pale brownish hairs; the tarsal segments of the legs have darker scales or hairs. Hair brush is seen on the tibia instead of epiphysis. Hind legs are relatively very long (Fig. 1).

Venation. (Fig. 5a, b) Nine veins in the forewing, seven veins from the dc forewing. Veins M_1 and R_4+R_5 are shortly stalked, a median stem divided dc two halves. Veins M_{2+3} , CuA_1 and CuA_2 are short and parallel to each other. Hindwings are narrow and pointed, have seven veins and vein $Sc+R_1$ runs parallel to the costal margin. Vein R_s and M_1 are stalked. M_1 and M_2+M_3 run as a separate vein to termen. CuA_1 and CuA_2 are shortly stalked. Anal veins are very short.

Abdomen. Densely covered with scales, the anterior portion of the abdomen is covered with pale brownish scales and the last abdominal segments and the tip of the abdomen are covered with blackish-brown scales.

Genitalia. (Fig. 6 a, b) Elongated, 1 mm in length. Tegumen arched apically. Valva is short and symmetrical, at the apex with short setae. Saccus distally with some sharp, curved thorns. Vinculum is very long and V-shaped. Saccus long and pointed at the apex. Phallus tubular, with a pointed tip, length 0.8 mm. Gnathos and juxta absent.

Paratype ♀ (Fig. 2). Winged, wingspan 9.0–9.3 mm, body length 4.2 mm, forewing length 4.5 mm excluding fringes, forewing width 1.3 mm, forewing index 3.4 mm, eyes are large, ocular index 0.93 mm. Antenna thread-like with short cilia on segments. The head and area surrounding the eyes are densely covered with long golden hairs. abdomen is long and stout, pale yellowish thinly covered with scales. Wings are lanceolate and narrow with long fringes. Forewings are densely covered with pale golden-brown scales. Dark brown scales are present and form patches and spots on the forewings. Four dark patches which are vertically arranged on each forewing have been seen. When wings were folded close to the body, the spots on both wings came together to form a median band just

below the anterior end (Fig. 4). Hind wings are fully covered with pale whitish shiny scales without any markings. The wing venation is same as in males. Legs are elongated and covered with long shiny white scales. The last abdominal segment has a long hair tuft surrounding the genitalia and a long ovipositor extended outside the last abdominal segment.



FIGURE 3. Male dorsal view.



FIGURE 4. Female dorsal view.

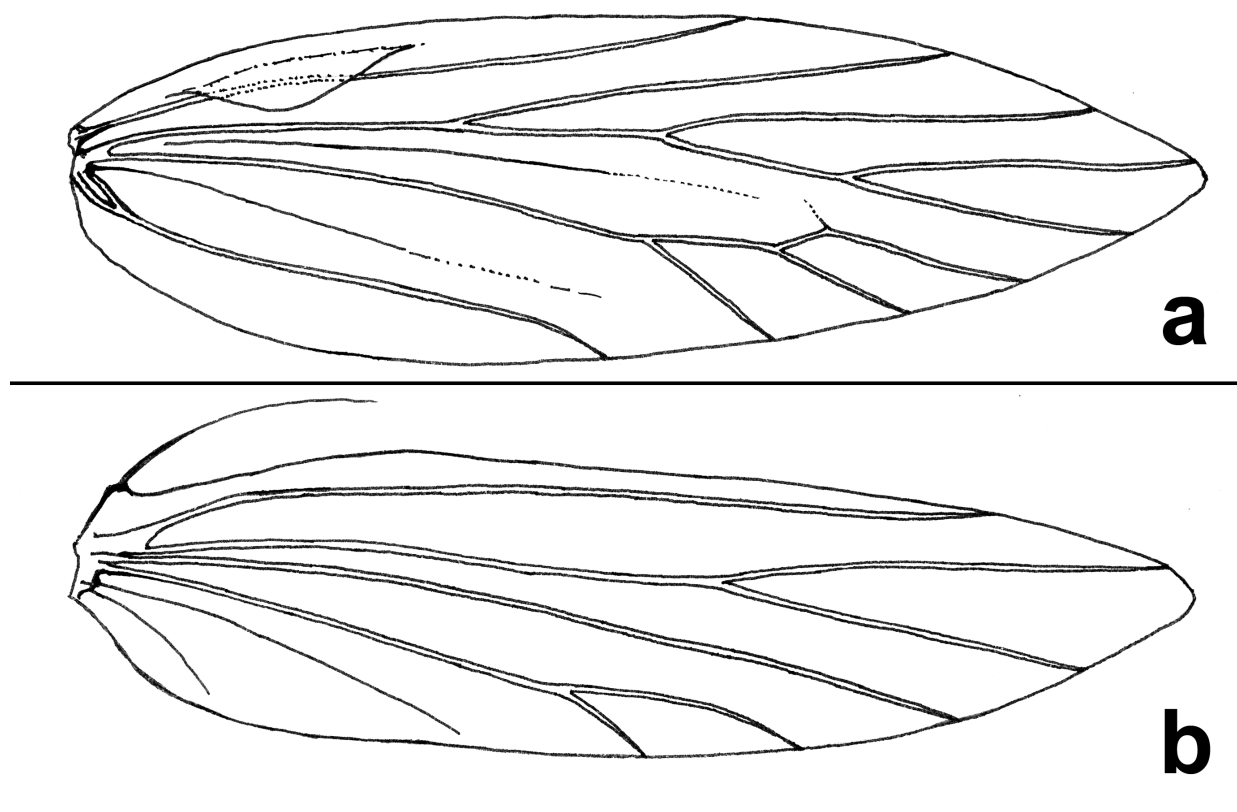


FIGURE 5. a. Forewing venation, b. Hindwing venation, drawing T. Sobczyk.

Larva: (Fig. 7 a, b; 8) Larva is pale yellowish, head is dark brown, highly sclerotized without any patches. A mature larva is 4 mm in length.

Larval cases and habitat: Larval cases were found attached to rocks covered with lichens. The larvae actively move on the surface of rocks and feed on lichen parts. The pupal bags are found colonizing as groups during pupation, attaching to each other in the lichen colony on the rocks. The pupal cases exhibit camouflage and are difficult to distinguish from the lichens (Fig. 12 a, b). Larval bags have a ‘witches’ hat’ appearance, a disc-like anterior and a tubular posterior part. The cases are built with silk, soil, rock and lichen particles and the colour of the cases resemble the lichen with which they have been associated. The male and female cases have size differences and they form pupal groups mixed with both sexes (Fig. 10). The adult male pupal case has a maximum length of 7 mm and width of 5.5 mm at the anterior end. The female pupal case has a maximum length of 9 mm and width of 6 mm at the anterior end.

Biology. Other species of subfamily Eumasiinae have been previously reported to inhabit rocks and their premises, and feed on the algae and mosses on the rocks (Saigusa & Sugimoto 2013; Roh & Byun 2016, Roh *et al.* 2018). Similarly, *Eumasia venefica* **sp. nov.** also feeds on the lichens and other materials present on the surface of the rocks.

The larval and pupal case structure is distinct and well-adapted for the protection of pupae during the metamorphosis into the adult. The larvae move on the rock surfaces and feed on the lichen cover. It drags its ‘witches’ hat’ shaped cases along as they move. The anterior wide end of the case covers the larval body while moving and acts as a shield or like an ‘umbrella’ over its body. The larvae directly attach the anterior part of the case during rest and pupation. The outer edges of the wide part are pasted on the rock surface with silken threads and form a ‘cup-shaped’ space anteriorly and this space acts like a brooding chamber or pupation chamber for the development of pupae into adult insects. The exoskeleton and head capsules of larvae after moulting will deposit into this space (Fig. 11). The posterior tube-like case is extended into this space and metamorphosis is completed at this extended tip of the case (Fig. 9). The male-female ratio at emergence was 1:1 (2 each) unlike other species of the region where females outnumbered the males.

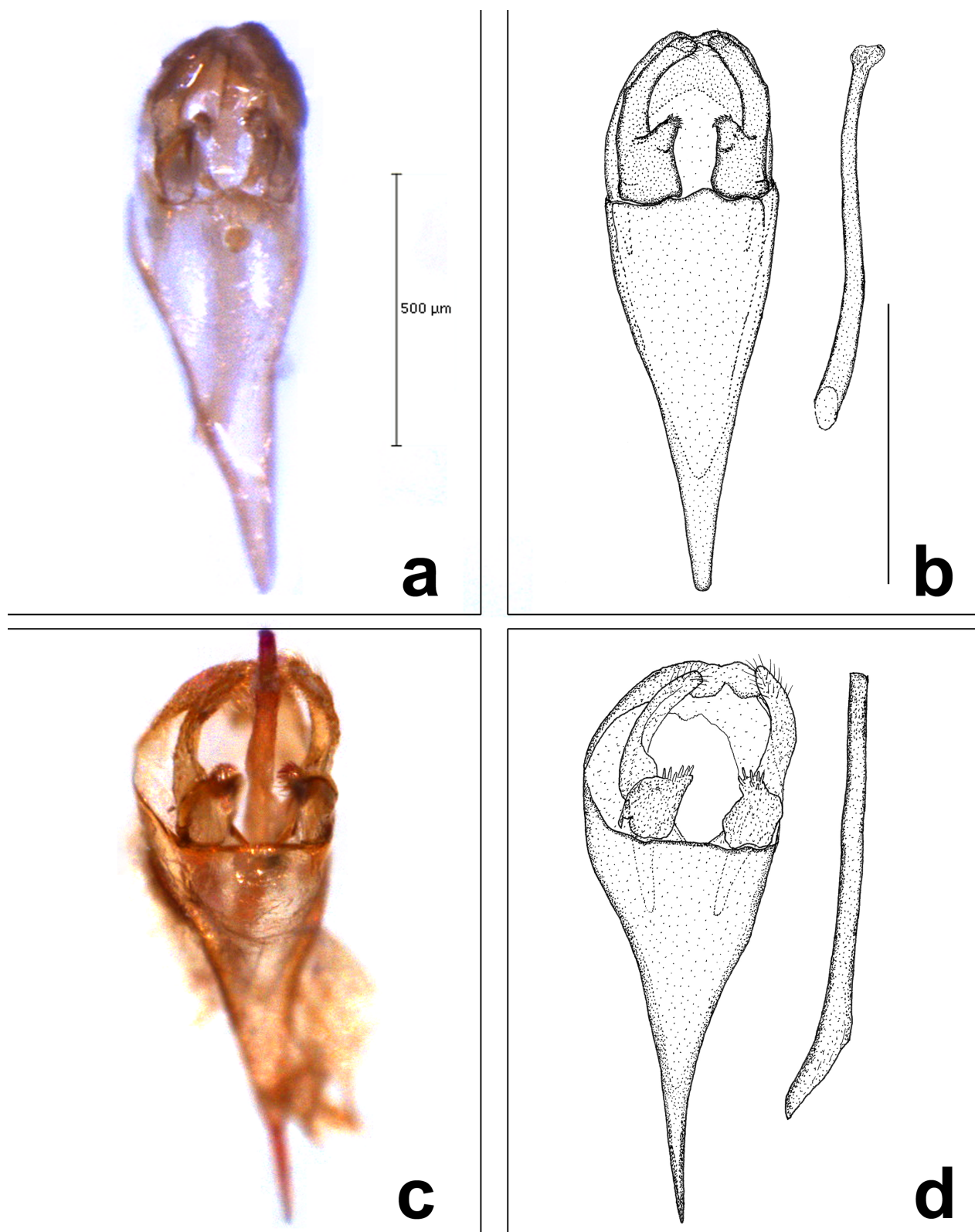


FIGURE 6. Male genitalia, a. genitalia of *Eumasia venefica* sp. nov., b. genitalia of *Eumasia venefica* **sp. nov.**, drawing T. Sobczyk c. genitalia of *E. thomasi* d. genitalia of *E. thomasi*, drawing T. Sobczyk.

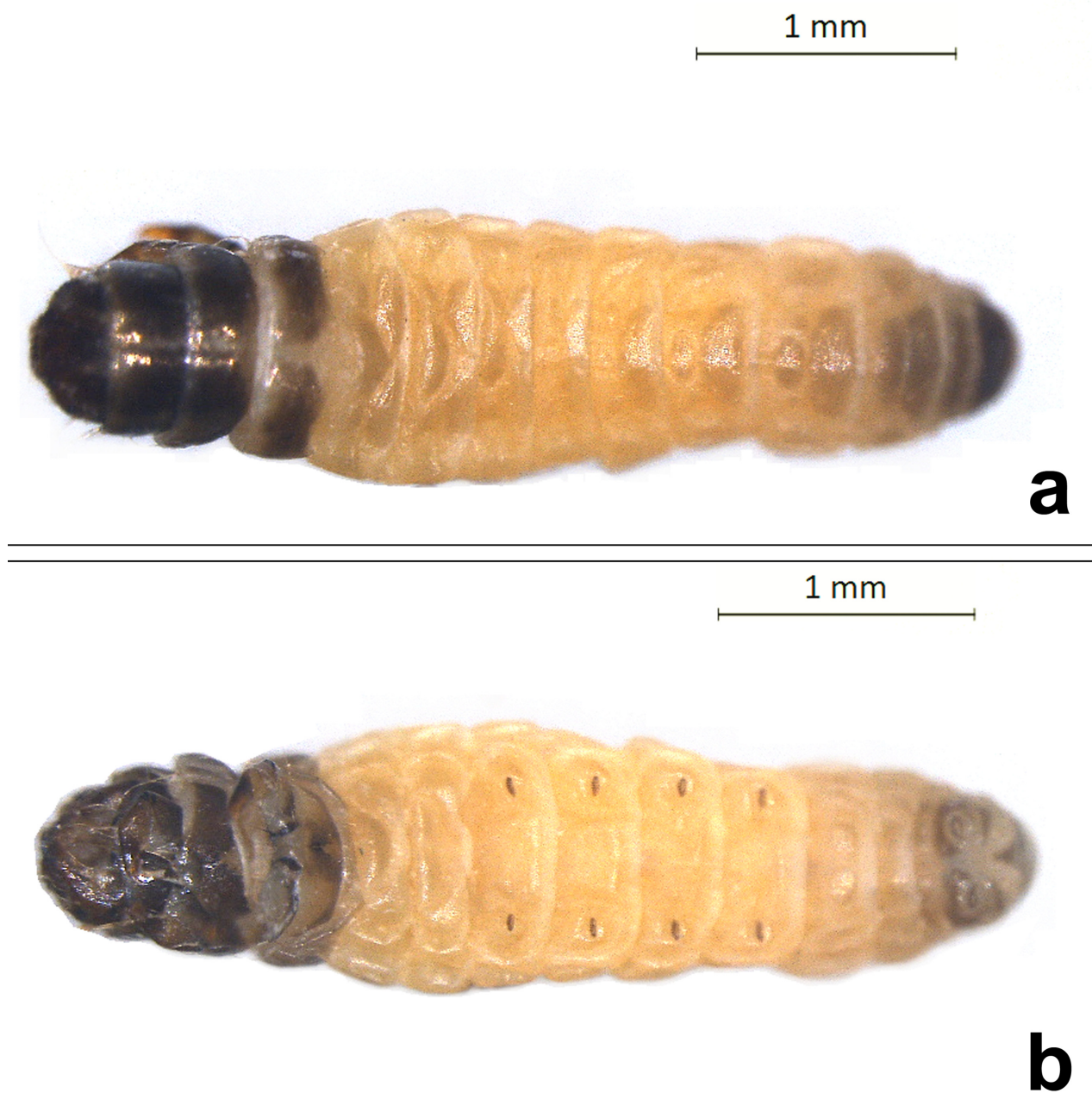


FIGURE 7. Larva a. dorsal b. ventral.

Distribution. Larval and pupal cases were collected from Nariyampara of Idukki, Kerala (Fig. 13). The collection site was at an altitude of 960 mASL. Soil Maps of India (1996) describe the soil of the region as ‘Clayey mixed ustic pale humults and rock land (very deep, well-drained, clayey soil on moderately steeply sloping high hills with thin vegetation, with moderate erosion, associated with rock outcrops and deep well-drained gravelly loam soils on gentle slopes). Average temperature is 20°C. Summer temperatures range from 19°C to 29°C and winter temperatures fluctuate between 15°C to 24°C. The Centre for Earth Studies Resource Atlas of Kerala (1994) records average rainfall at Nariyampara was South West Monsoon 150 cm and Northeast Monsoon 40 cm and ‘Other rains’ was reported as 30–50 cm.

DNA barcode and phylogenetic analysis. COI sequencing of the species was done and the sequence has 655 base pairs. The sequence was uploaded to the NCBI GenBank with the accession number OR044899. The BLAST search results of the sequence show 93.59% sequence similarity with *Eumasia thomasi* (OP302728) from India and 89.88% with *Eumasia muscella* (LC094210) from Japan.

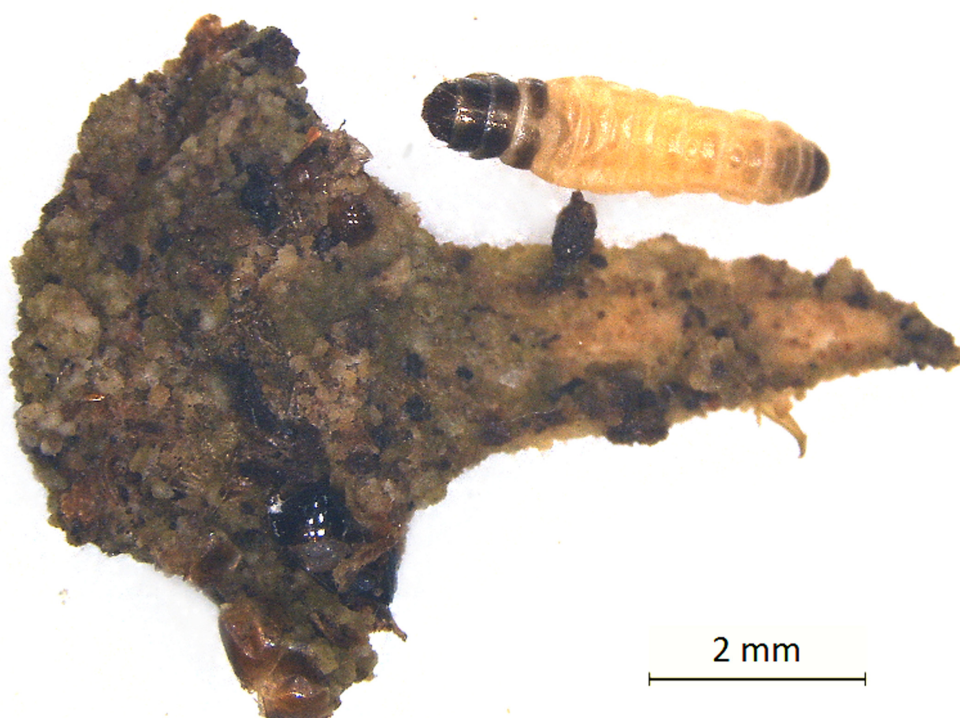


FIGURE 8. Larva with case.

The tree (Fig. 14) with the highest log likelihood (-1709.54) is shown. The percentage of similarity between each taxon and taxon cluster is shown next to the branches. *Eumasia venefica* **sp. nov.** shows the highest relation with *Eumasia thomasi* from Kerala, India. This cluster shows higher affinity to the branch having *E. muscella* and *E. viridilichenella* (both species reported from Asia). Detailed discussion of the eastern and western group of *Eumasia* following Hättenschwiler (1998) has been presented by Usha *et al.* (2022b).

Diagnosis. *Eumasia venefica* **sp. nov.** differs from *E. thomasi* (Usha *et al.* 2022b) from Kerala, India by wing venation, wingspan and larval case structure. No veins are stalked in *E. thomasi*, whereas veins R_{4+5} and M_1 are shortly stalked in *Eumasia venefica* **sp. nov.** The wingspan between male and female *Eumasia venefica* **sp. nov.** has a 1 mm difference (M: 8–8.2, F: 9–9.3) whereas both sexes in *Eumasia thomasi* have a lesser difference in wingspan (M: 8–8.2, F: 8–8.8). *Eumasia venefica* **sp. nov.** flies in October and November but flights were observed in *E. thomasi* during January and July. Walker (1964) described *E. arenatella* with a wingspan of 12.6 mm which is much larger than *E. venefica* **sp. nov.** *E. arenatella* was reported from Eastern Himalayas from an altitude of 5000 ft Meyrick (1910). *E. arenatella* had six forewing dc veins (Hättenschwiler 1998) which is one less than *E. venefica*. Male moth of *E. exoria* reported from Bengal had a larger wingspan than *E. venefica*. Venation has not been described. (Meyrick, 1911, 1919). Flight time of both these species also differed from *E. venefica* **sp. nov.** (Table 2). Colour and markings are also different with both *E. arenatella* and *E. exoria* being much paler. Meyrick (1919) describes *E. exoria* with “markings dark fuscous; five roundish spots on costa, two in the disc at middle and $\frac{3}{4}$ (representing stigmata), and several small elongate marks on posterior part of dorsum and termen. Cilia whitish, basal half barred dark fuscous irroration” which is different from *E. venefica* **sp. nov.**

E. muscella Saigusa & Sugimoto, 2005 (Roh *et al.* 2018) from Japan and South Korea also differ in forewing venation - the veins R_{4+5} and M_1 , M_{2+3} and CuA_1 are stalked in *E. muscella*.



FIGURE 9. Pupal exuvia at the posterior end of the case.



FIGURE 10. Male and female pupal cases attached to each other.

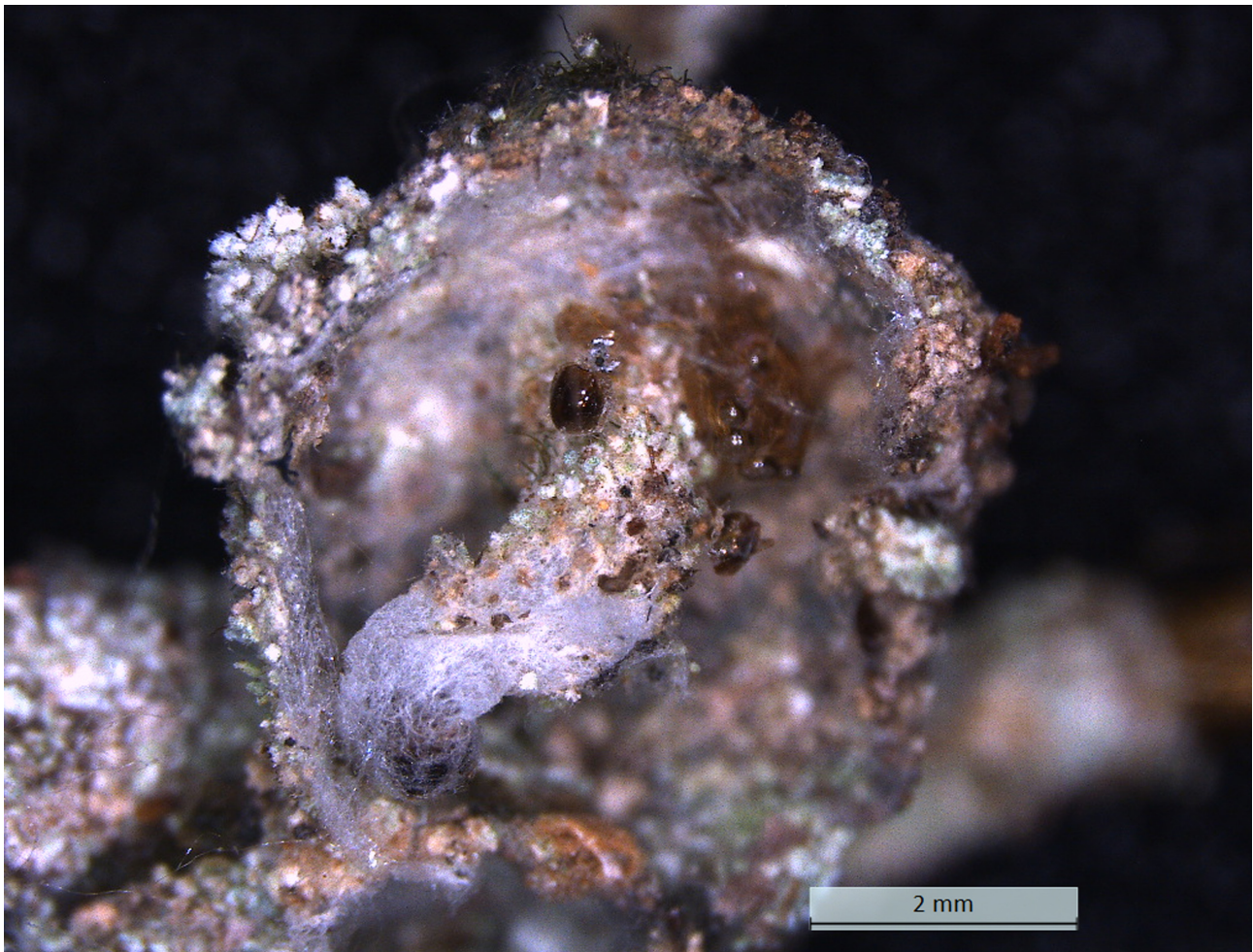


FIGURE 11. Cup shaped region of the pupal case, head capsules and other remnants seen in this space.

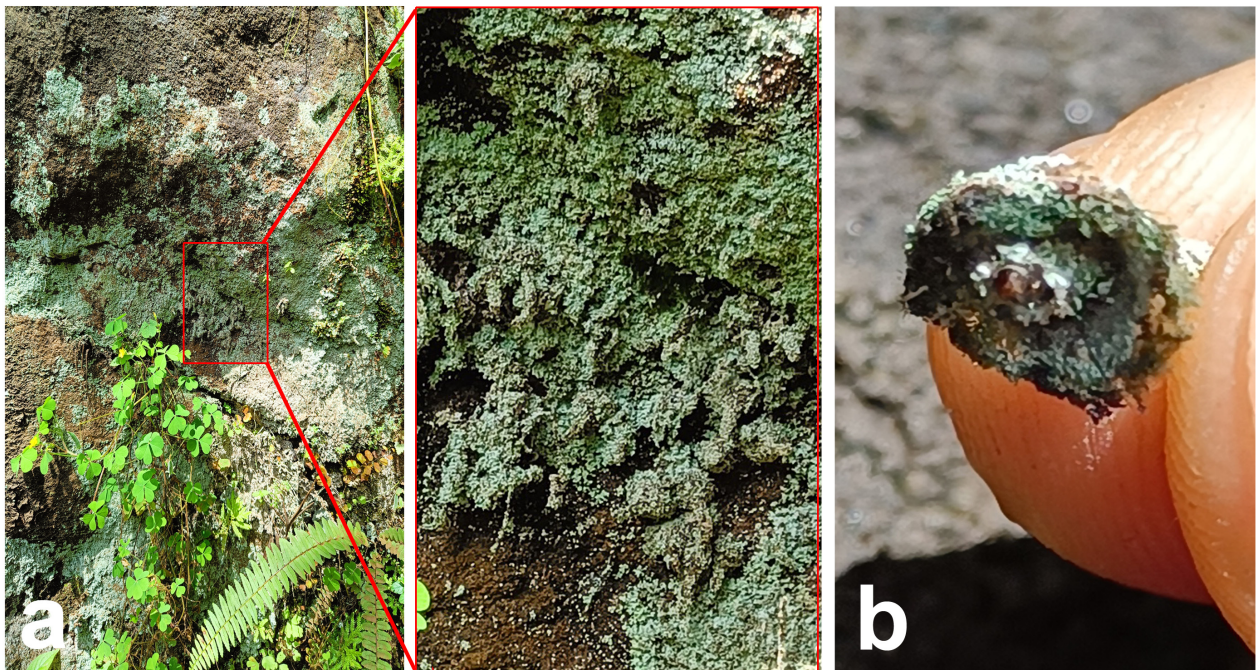


FIGURE 12. Larval habitat; a. Larval case clustering as a colony on lichen covered rock. B. Larva protruding out of the anterior opening of case seen built with lichens.

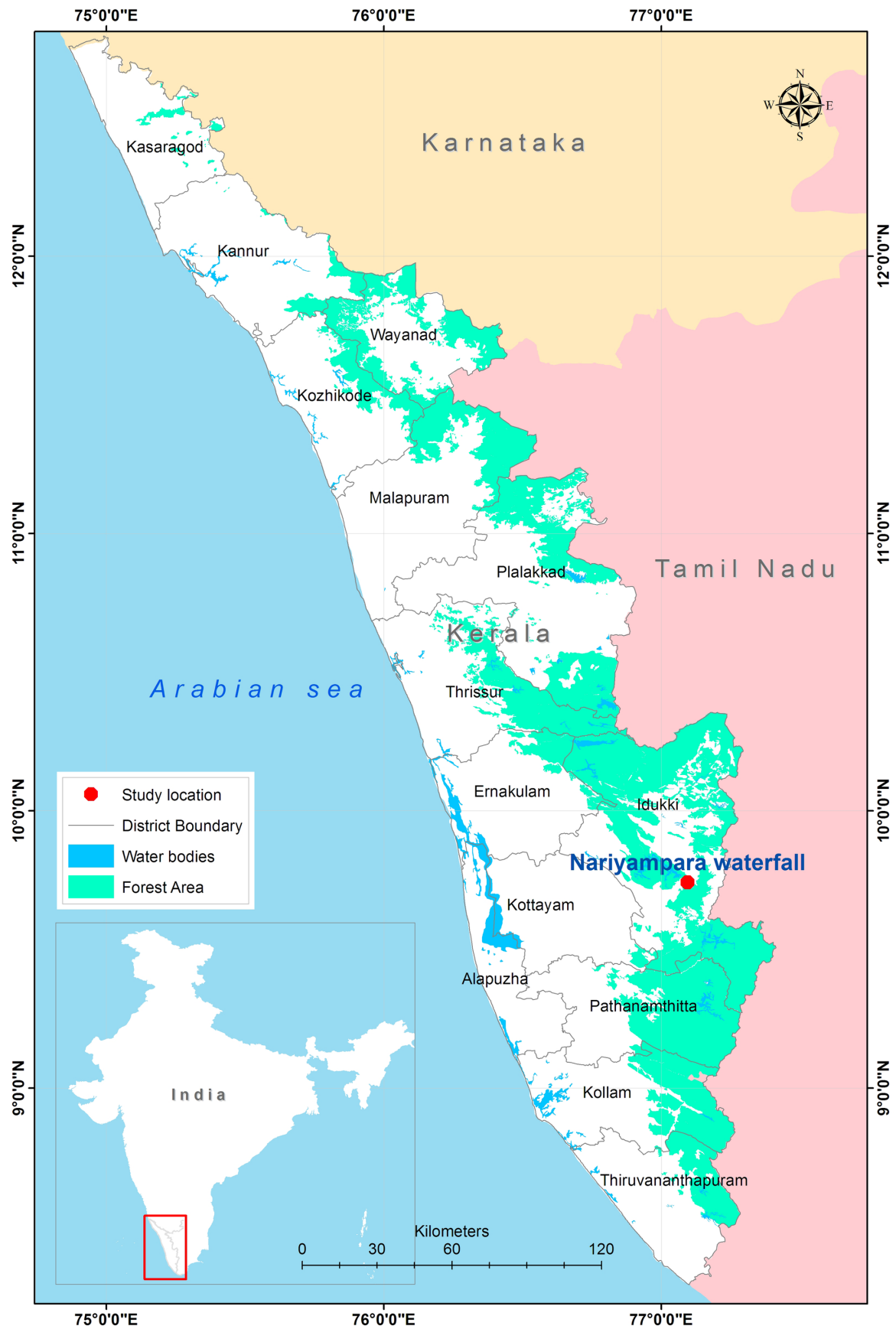


FIGURE 13. Map showing location of type locality.

TABLE 2. Overview of *Eumasia* species in Asia.

Eumasia	Distribution	Wingspan (mm)	Length larval case (mm)	Veins from forewing dc	Colour hindwing	Fly time (month)
<i>venefica</i> sp. nov. (Present study)	India, Kerala	M: 8–8.2 F: 9–9.3	M: 7 F: 9	7	brownish- white	10, 11
<i>thomasi</i> (Usha <i>et al.</i> 2022)	India, Kerala	M: 8–8.3 F: 8–8.8	M: 8.5–11 F: 11.5–13	7	white greyish	1 and 7
<i>arenatella</i> (Walker, 1864)	Sri Lanka (Ceylon), India, Dar- jiling	M: unknown F: 12,7 (6 lines)	unknown	6	white	3–4 and 9
<i>cryptiphila</i> Meyrick, 1919	Sri Lanka (Ceylon, Galle)	M: 7–9 F: 7–9	unknown	?	dark grey	1
<i>exoria</i> Meyrick, 1919	India, Bengal, Pusa	M: 9 F: unknown	unknown	?	whitish-grey	9
<i>muscella</i> Saigusa & Sugimoto, 2005	Japan, Honshu, Kyushu	M: 9.1–10.2 F: 9.5–11.3	M/F: 8.5–9.5	7	pale yellow white	7
<i>parvulella</i> Walker, 1863	Sri Lanka (Ceylon)	M: 7,4 (3,5 lines) F: unknown	unknown	?	pale grey (?)	?
<i>testata</i> Meyrick, 1911	Sri Lanka (Ceylon, Peradeniya and Madulsima)	M: 9.5–10.5 F: 11–12.5	M: 10.5–11 F: 11–16	?	pale grey	3
<i>viridilichenella</i> Saigusa & Sugi- moto, 2005	Japan, Honshu, Kyushu	M: 8.2–10.1 F: 8.5–10.2 mm	M/F: 8–9	7	dark grey	6–7
<i>ziegleri</i> Hättenschwiler, 1998	Maldives, North-Male-Atoll	M: 5.5–7.5 (average 5,7) F: 7–8	M: 5.5–6.5 F: 6.5–7.5	7	brown	6
<i>montanella</i> Solyanikov, 1986	Tajikistan	10–10.8	9–12	7	grey	6

Discussion

Eumasia venefica **sp. nov.** is distinct from other recorded species of the same genus in morphology, forewing venation, wingspan and genital characteristics. COI sequence is distinct from species in the genus. The habitat and larval case structure of *Eumasia venefica* **sp. nov.** is also unique from others. The new species has an association with lichens which has been reported previously in the *Eumasia* species worldwide (Hättenschwiler 1998). Psychid species with lichen interaction belonged to the subfamilies: Naryciinae Tutt, 1900, Taleporiinae Herrich-Schäffer, 1857, Typhoniinae Lederer, 1853, Epichnopteryginae Tutt, 1900, Oiketicinae Herrich-Schäffer, 1855, Psychinae (Davis 1964; Arnscheid & Weidlich 2017) and Scoriodytinae (Hättenschwiler 1989). Biology and larval food are largely unknown in Placodomininae (Sauter & Hättenschwiler, 1991, Arnscheid, 2020) and Arrhenophaninae (Walsingham, 1913). *Eumasia venefica* **sp. nov.** interacts with lichens for making cases and feeding. The camouflage with the lichens and the shape of the larval case helps them to stay hidden from predators.

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Capulopsyche keralensis gen. et sp. nov., a new genus and species of the subfamily Taleporiinae (Lepidoptera: Psychidae) from Kerala, India

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Abstract

A new genus and species, *Capulopsyche keralensis* gen. et sp. nov. from the subfamily Taleporiinae is described from Kerala, India. The new genus has distinct features from other genera of the subfamily. Double-walled larval case architecture is one of the unique characteristics of this genus. Details of life stages, distribution, COI sequencing, and the morphology of adults are described in the paper.

Key words: Bagworm, Psychidae, COI, Taleporiinae

Introduction

Bagworm moths belong to the family Psychidae characterized by the construction of bags or cases which they carry around their bodies during larval stages (Rhainds *et al.* 2008). There are 241 genera and 1450 species identified from all over the world (Nieukerken *et al.* 2011; Sobczyk 2011, 2019).

During field visits to Idukki in 2021 and 2022 many larval and pupal cases showing appearance distinct from other species reported from the region were observed hanging on plants. The cases were collected and reared in laboratory conditions. The hatched adults showed characteristics of the subfamily Taleporiinae (Herrich-Schäffer, 1857).

Ten genera with 67 species have been described worldwide from the tribus Taleporiini (Sobczyk 2011 and additions from own database) of which sixteen species are from Asia (without Russia). Only one species has been reported from the Indian subcontinent: *Altobankesia cavernicolella* Dierl, 1966 from Nepal, only known from the type locality Khumjung (3,800 m). Five species have been described from Japan: *Kozhantshikovia vernalis* Saigusa, 1961, *Kozhantshikovia aestivalis* Saigusa, 1961, *Taleporia nigropterella* Saigusa, 1961, *Taleporia amariensis* Saigusa, 1961 and *Taleporia shosenkyoensis* Saigusa, 1961. *Talaeporia isozopha* Meyrick, 1936 has been reported from China. Species reported from Southeast Asia are *Taleporia subaenea* (Meyrick, 1921), *Taleporia corusca* Sobczyk, 2010, *Taleporia epomias* (Meyrick, 1921) *Taleporia inopinata* Sobczyk, 2010 and *Taleporia reticulata* Sobczyk, 2010. Four species have been described from Western Asia: *Bankesia pallida* (Staudinger, 1879) and *Taleporia pseudoimprovisella* de Freina & Witt, 1984 from Turkey, *Sciopetris amseli* Sieder, 1959 from Afghanistan, and *Solemasia araxella* Zagulyaev, 1996 from Azerbaijan (genus *Solemasia* belongs probably to Placodrominae, see Arnscheid, 2020).

The characteristics of Taleporiinae shown by the specimens were: Males were winged moths. Females were wingless, with legs and short antennae. The antenna was filiform. Further examination showed that the specimens belonged to a new genus and species which are described in this report.

Materials and methods

Fifty-three pupal cases were collected from Nariyampara, Idukki district of Kerala. Similar types of larval cases were also observed at Nelliampathy hills and six larval cases were collected. All the cases were reared in the laboratory until the emergence of adults. Both males and females emerged from the cases collected from Nariyampara and no emergence of adults was observed from the cases collected from Nelliampathy. The emerged adults were examined and external characteristics were noted. Microscopic slides were prepared to study the wing venation, genitalia, antenna, and wing scale structures. Photographs of the specimens were taken by using the DFC450 camera of the Leica M205C stereomicroscope and Leica S8APO stereomicroscope.

COI Gene Sequencing: Larva was used to extract the DNA. Larvae from both localities were sequenced. The DNA extraction and Sequencing of the mitochondrial cytochrome oxidase I gene were done at the RGCB, Trivandrum. The forward and reverse primers used were LCO and HCO respectively (Folmer *et al.* 1994). Forward and reverse reads were assembled following Drummond *et al.* (2010). The evolutionary relationship was inferred using the Neighbor-Joining method (Saitou & Nei 1987). The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (300 replicates) are shown next to the branches (Felsenstein 1985). The tree is drawn to scale, with branch lengths (next to the branches) in the same units as those of the evolutionary distances used to infer the phylogenetic tree. The evolutionary distances were computed using the Maximum Composite Likelihood method (Tamura *et al.* 2004) and are in the units of the number of base substitutions per site. All ambiguous positions were removed for each sequence pair (pairwise deletion option). There was a total of 692 positions in the final dataset. Codon positions included were 1st+2nd+3rd+Noncoding. This analysis involved 25 nucleotide sequences of which 23 sequences were retrieved from NCBI GenBank and BOLD SYSTEMS. Outgroup taxa were *Manatha albipes* Moore, 1877 and *Eumeta crameri* Westwood, 1854 of the subfamily Oiketicinae, and 3 species of the genus *Eumasia* Chrétien, 1904 from the subfamily Eumasiinae. Evolutionary analyses were conducted in MEGA11 (Tamura *et al.* 2021).

Abbreviations

RGCB	Rajiv Gandhi Centre for Biotechnology, Trivandrum
NCBI	National Centre for Biotechnology Information, Bethesda, Maryland, USA
BLAST	Basic Local Alignment Search Tool
EI	Eye-Index (Smallest eye distance / vertical eye diameter in anterior view)
WI	Wing-Index (maximum length base to apex divided by the maximum width)

Taxonomy

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1834

Subfamily Taleporiinae Herrich-Schäffer, 1857

Tribe Taleporiini Herrich-Schäffer, 1857

Capulopsyche gen. nov.

Type species. *Capulopsyche keralensis* sp. nov.

Diagnosis. Males with fully developed wings, females wingless, without ocelli. Within Taleporiini, the number of veins from the forewing dc varies by genus. None of the Palaearctic and oriental Taleporiini genera have nine of forewing dc veins and five dc-veins in the hind wing. This characteristic is unique to *Capulopsyche* gen. nov. The other genera (*Bankesia* Tutt, 1899, *Kozhanchikovia* Saigusa, 1961 and *Altobankesia* Dierl, 1966) have six dc-veins in the hind wing. On the other hand, genera with five dc-veins in the hindwing are distinguished by fewer

dc-veins in the forewing: *Sciopetris* Meyrick, 1891 with eight and *Solemasia* Zagulajev, 1996 with seven veins. The three genera from Southern Africa, *Barbaroscardia* Walsingham, 1891, *Lythrophila* Meyrick 1918, and *Thranitica* Meyrick, 1908 have six dc-veins in the hind wing. While *Bankesia* and *Altobankesia* have an additional cell in the dc forewing, *Kozhantshikovia* and *Solemasia* Zagulajev, 1996 lack it. *Kozhantshikovia* has very narrow, Y-shaped scales and a long saccus, in *Pseudobankesia* Meier, 1963, *Taleporia* Hübner, [1825], *Bankesia* Tutt, 1899, and *Sciopetris* Meyrick, 1891 the scales are very wide and the saccus is shorter. The larval cases differ significantly from the other known Taleporiini larval cases. The cases are double-walled. The inner case is tubular and its lumen is round. The outer case is wide with a curved top. It is shorter than the inner case. The larval cases are hung on threads for pupation.

Etymology: *Capulo* (Latin) coffee refers to the moth being recorded from coffee plantations and to the predominant colour of the moth and *psyche* (Latin) butterfly, psychid.

Description. Male. Head. Vertex and frons covered with semi-erect scales, and a tuft of hairs projecting dorsally in the frons area. Occiput with densely arranged narrow scales with bidentate apices, and these scales are also present in the surrounding areas of eyes, Eyes small, additional ocelli absent. Labial palpi curved upwards, three-segmented. Antenna short, the filiform segments ciliated on both sides and dorsally with small scales.

Thorax. Barely covered with scales on the dorsal side. The forewings and hindwings are thickly covered with scales, the outer margins of both pairs of wings have fringes, the forewing fringes are short and broad, and the hindwing fringes are distinctly narrower and long. Forewings nearly oval-shaped, WI 2.6 mm. Nine veins arise from forewing dc, accessory cell absent. The hindwings are shorter than the forewings, length of 2.9 mm including fringes, WI 2.92 mm. Five veins arise from hindwing dc, and frenulum as a single bristle. Forelegs with a long hairbrush originating from the middle length of the tibia and extended along with the tarsal segments. Midlegs with one pair, hindlegs with two pairs of tibial spurs. Spurs of each pair of clearly different lengths.

Abdomen. Densely covered with scales, length 1.5 mm.

Genitalia. Tegumen elongated, posterior margin arched, deeply notched in the middle, ending in two curved thorns. Vinculum short, V-shaped, saccus short and pointed.

Female. Wings reduced to tiny, structureless lobes, without scales. Antenna short, eyes present. Legs with reduced tarsal segments.

Capulopsyche keralensis sp. nov.

(Figs. 1–10)

Type material. Holotype, ♂ India, Kerala, Idukki, Nariyampara, 9.7424° N, 77.0939° E, 28.xi.2022, with larval case, leg. Usha A U (Fig. 1). Holotype will be deposited at the Zoological Survey of India Museum, Calicut, Kerala after submission of thesis of the first author and is at present at St. Thomas College, Thrissur.



FIGURE 1. ♂ Holotype of *Capulopsyche keralensis* gen et sp. nov. currently at STC Thrissur India.

Paratypes: 2 ♀, (both with larval case) same data as holotype, 16.xii.2021, leg. Usha, A. U. (Fig. 2 a–b); 2 ♂ (both with larval case) same data as holotype, 30.xi.2022, leg. Usha, A. U.; additional 24 larval cases with pupal exuviae, same data as paratypes, leg. Usha, A. U.; 4 larval cases with pupal exuviae, Nelliampathy, Palakkad, Kerala, 10.5013° N, 76.6768° E, 15.ii.2022, leg. Usha, A. U. (Figs. 2 a–b).

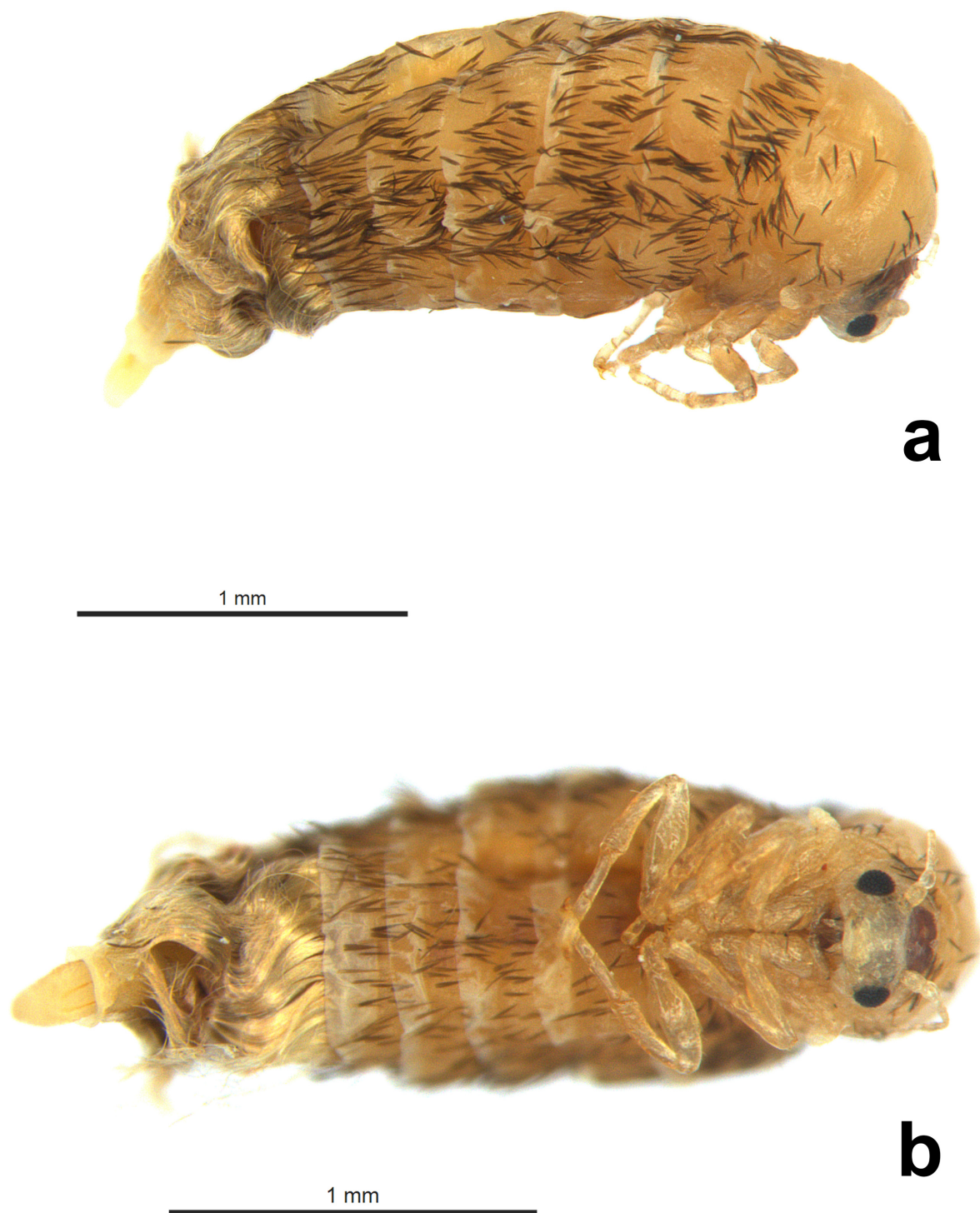


FIGURE 2. ♀ Paratype of *Capulopsyche keralensis* **gen et sp. nov.** at STC Thrissur. a. lateral view b. ventral view.

Diagnosis. See the diagnosis for the genus.

Etymology. The specific epithet *keralensis* is derived from the state of Kerala in India. The binomial *Capulopsyche keralensis* means ‘coffee psychid of Kerala’.

Description. Male. Small-sized brownish black moth, wingspan 8–8.4 mm, body length 2.9 mm, forewing length 3.7 mm including fringes, width 1.4 mm.

Head. Vestiture yellowish brown, the base of the antennae thickly covered with dark yellowish-brown scales with bidentate apices. Antennae total length 1.7 mm, flagellomeres with 24 segments (Fig. 3). EI 1.13 mm.

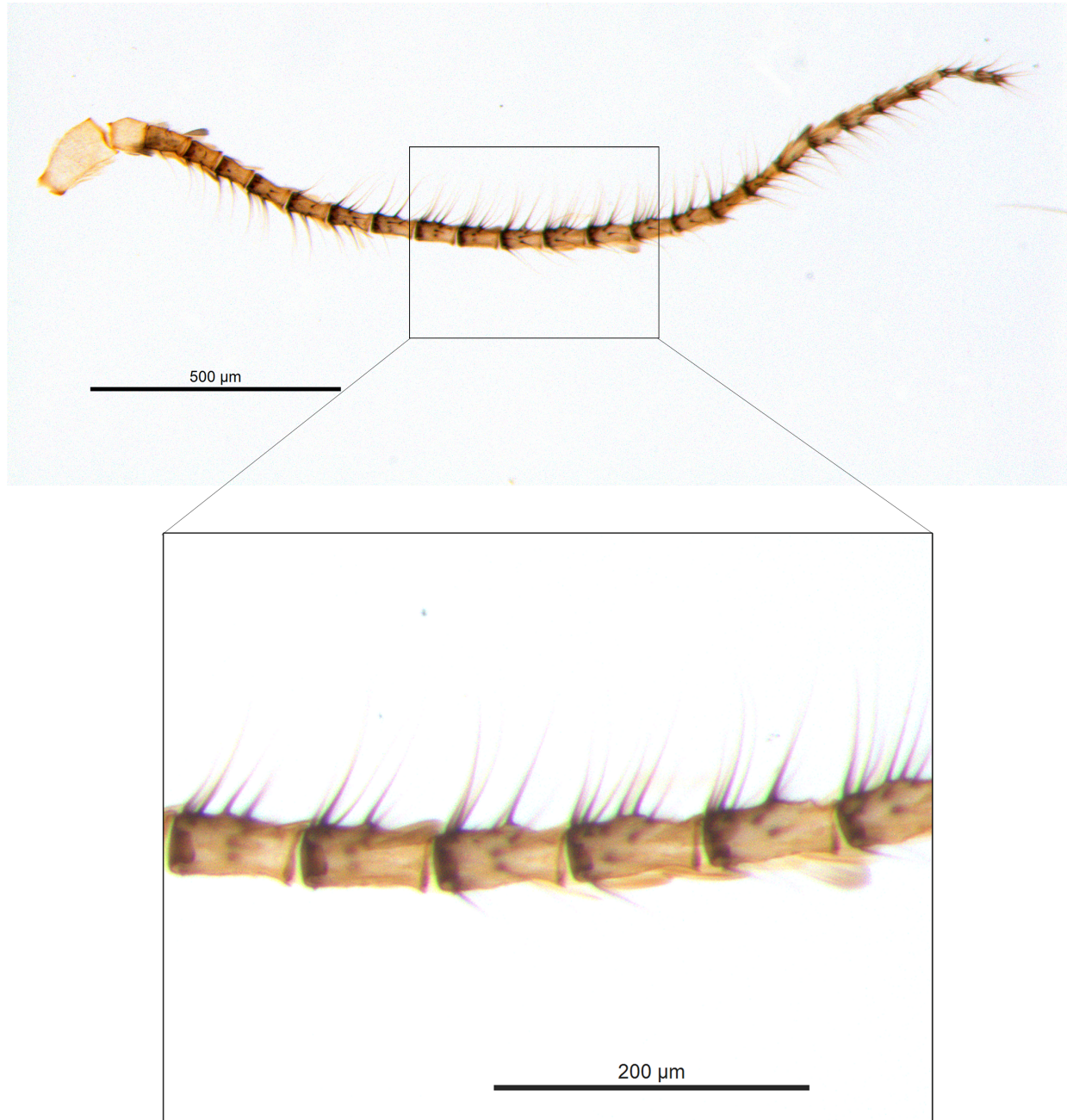


FIGURE 3. ♂ Antenna.

Thorax. Reddish brown, barely covered with scales on the dorsal side. Forewings covered with dark brown scales mixed with yellowish scales (Fig. 4). Scales broad (class 5–6), with 5–8 tips. The darker scales are mainly in the area of the front and outer margin and are partly arranged in irregular transverse bands. Fringes dark, wide, multi-pointed Hindwings dark greyish brown (Fig. 4), slightly lighter at the base. Width 1.4 mm, WI 2.6 mm. Wing venation as described for genus (Figs 5 a–b).



FIGURE 4. ♂ a. forewing, b. hindwing.

Abdomen. Small, covered with blackish scales, length 1.6 mm.

Leg. As described for the genus (Figs 6 a–c).

Genitalia. Length 0.46 mm. Valva broad, curved inwardly, surmounting the posterior border of the tegumen, rounded distally, with numerous setae. Saccus attached basally, ending in a strong curved spine. Phallus short, tubular, length 0.23 mm. (Fig. 7).

Female. Length 2.5–3 mm. Body pale yellowish, around the abdomen loosely covered with very narrow, distally rounded brownish black scales. Eyes are very small, EI 2.3 mm. Legs short, reduced. Femur and tibia present, tarsi reduced to 2–3 segments, with two prominent claws, pale yellowish brown. Antenna short, filiform, 0.5 mm long, with 6–9 different scaled segments. The two basal segments are wider than the others. The distal end of the abdomen with long ovipositor, surrounded by an anal hair-tuft consisting of long golden-brown hairlike scales.

Larva. (Fig. 8a and b) Body whitish cream, head distinctly sclerotized, first and second thoracic segment dark brown, strongly sclerotized dorsally, third thoracic segment more strongly sclerotized at the posterior margin. The abdominal segments were without sclerotized fields, the anal shield only slightly more sclerotized. Fully grown larva 4 mm in length.

Male and female pupal exuvia. (Figs. 9 a–b) Dark golden-brown, male exuvia 3.0–3.5 mm in length and 1 mm in width, female exuvia 3.8–4.0 mm in length and 1.5 mm in width.

A single row of spines dorsally on abdominal segments IV–VIII. The spines are directed backwards. Each row is comb-like and with numerous tiny hair-like spines. These spines probably serve to fix the pupa, and later to move it towards the exit and to hold it in place during emergence. In female pupae, the spines are shorter and reduced.

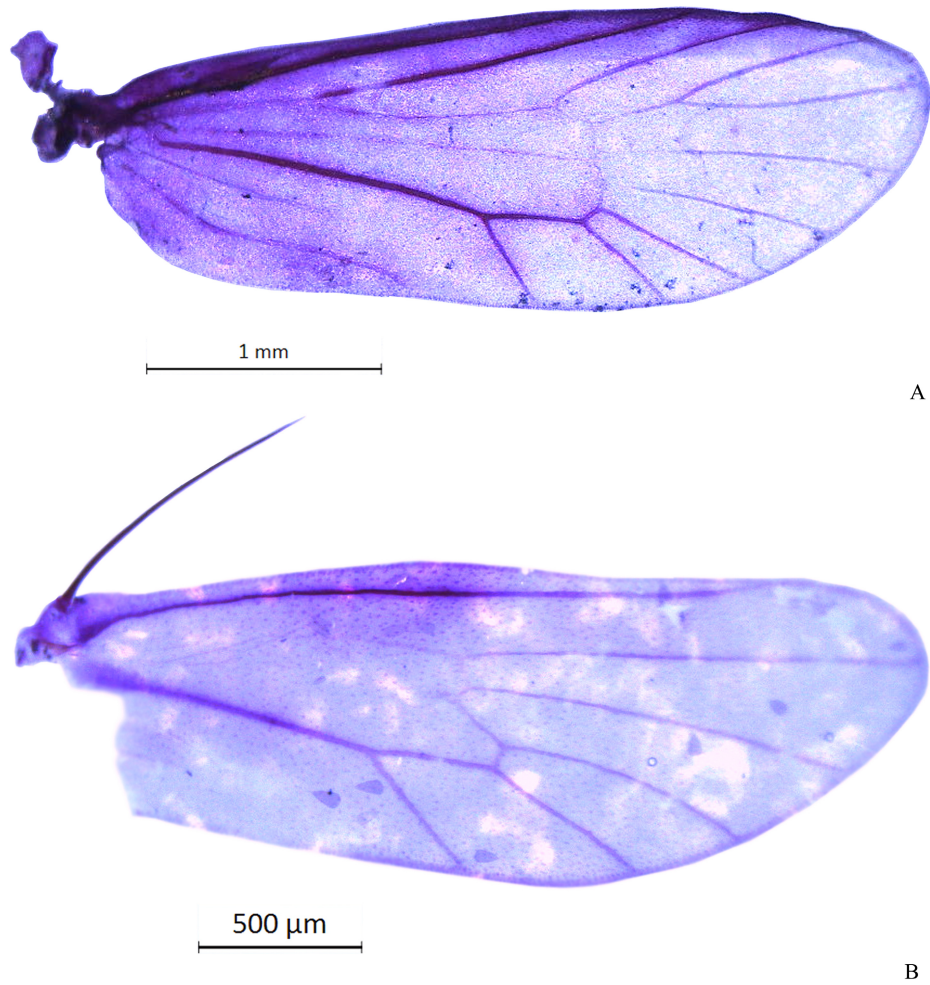


FIGURE 5. ♂ Wing venation a. ♂ Forewing venation descaled coloured in Fuch sine, mounted in alcohol. b. ♂ Hindwing venation descaled coloured in Fuch sine, mounted in alcohol.

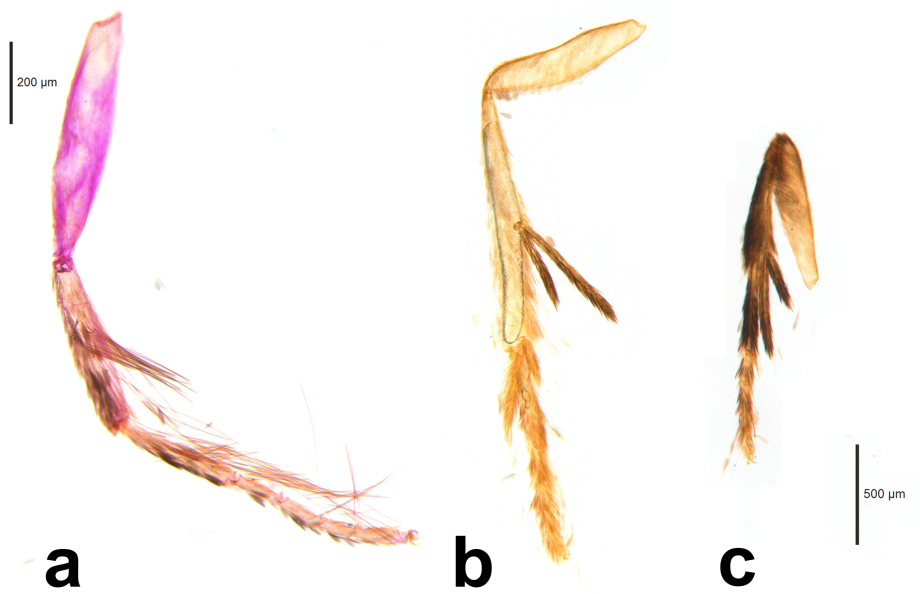


FIGURE 6. ♂ a Foreleg b. Hindleg c. Midleg ; coloured in Fuch sine, mounted in alcohol.

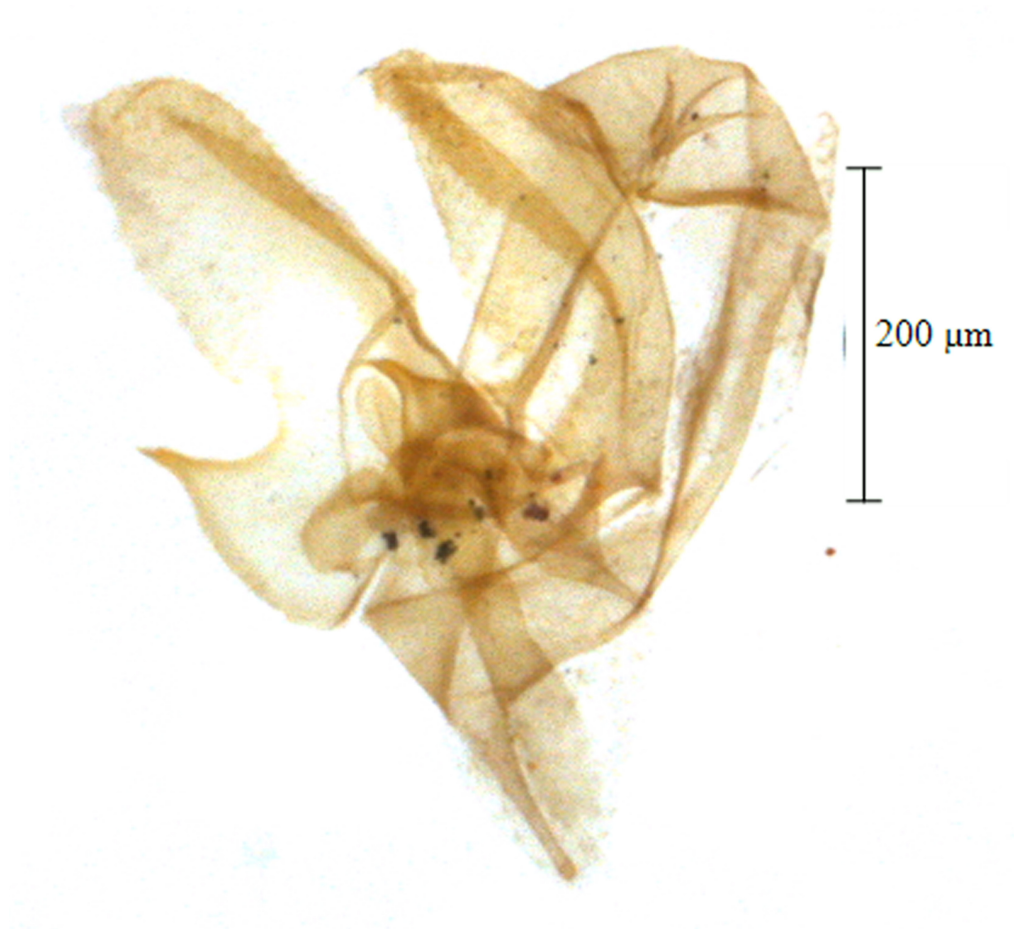


FIGURE 7. ♂ Male genitalia.

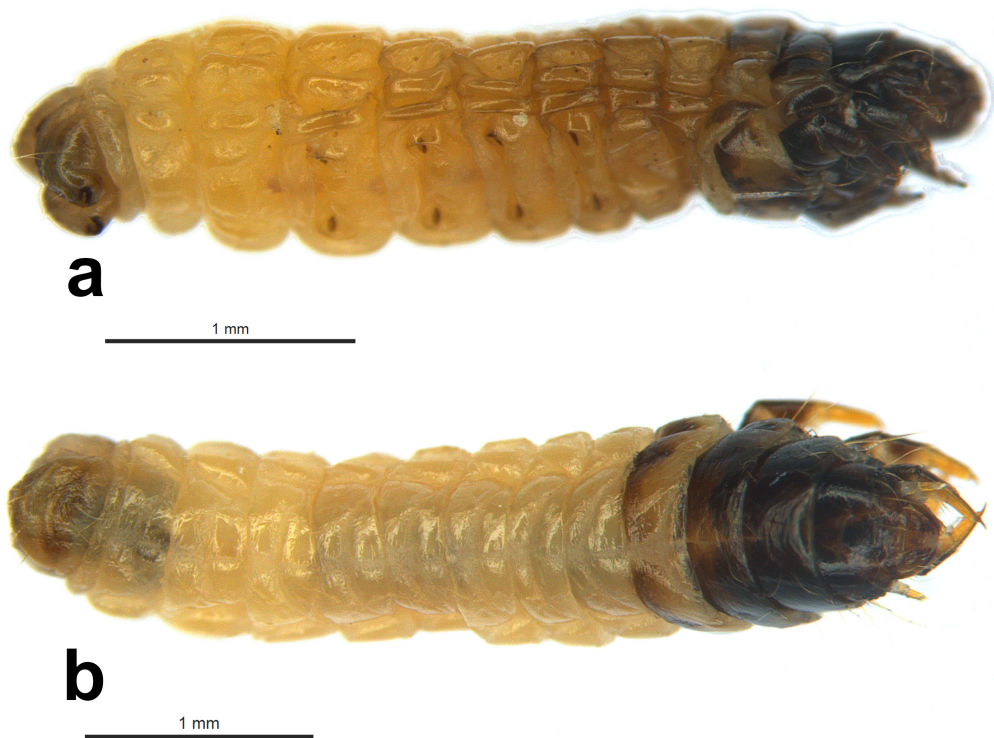


FIGURE 8. Larva a. ventral b. dorsal.

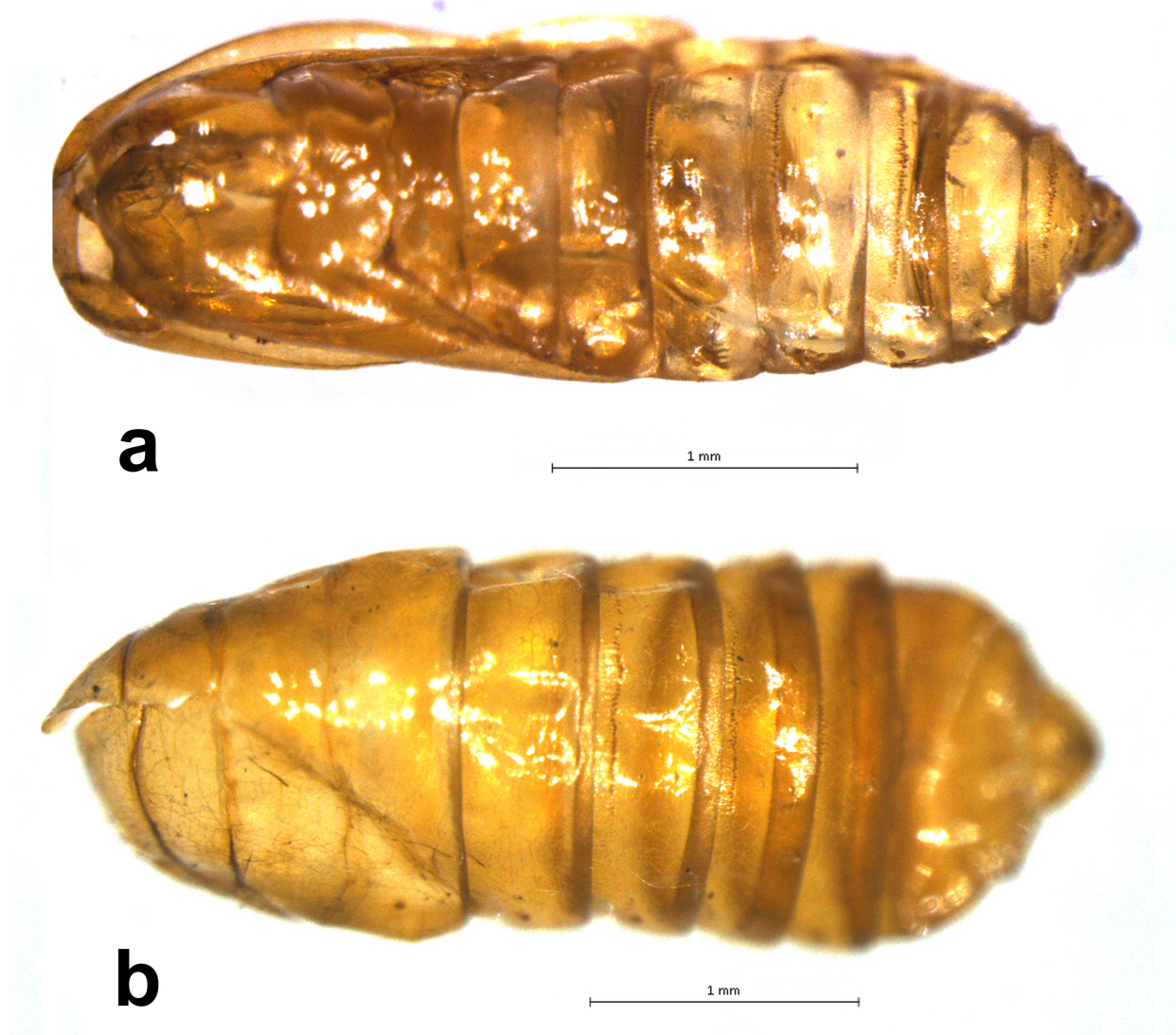


FIGURE 9. Pupal exuvia a. male b. female.

Larval case. (Figs. 10 a–b) The larval case of this species is an elongated tube-like, wrapped with a sheath made up of bark tissues from the trees. An adult male case has a length of 12–13 mm, and the width of the outer sheath is 5–6 mm. Female case has a 15–16 mm length and 6–7 mm width, and the attached thread of each case is 7–9 mm long. Double-walled larval cases reported from Psychidae are the triangular larval cases of *Diplodoma* Zeller, 1852 which also hung up on threads. But in *Diplodoma*, the inner case has a distinctive triangular shape and is not visible from the outside. The outer case also has a triangular basic shape in cross-section.

Distribution. Larval and pupal cases were collected from the coffee plantations of two localities from Kerala state, Nariyampara and Nelliampathy of Idukki and Palakkad districts (Fig. 11) respectively. Pupal cases were seen hung on the twigs and underside of leaves of the *Coffea arabica* plant (Fig. 12). Altitude at the sites of the collection was 960 m and 887 mASL. Both collection sites were situated inside private coffee plantations. The soil type of the region is described as ‘Clayey mixed ustic pale humults and rock land (very deep, well-drained, clayey soil on moderately steeply sloping high hills with thin vegetation, with moderate erosion, associated with rock outcrops and deep well-drained gravelly loam soils on gentle slopes) in Soil Maps of India (1996). In Nelliampathy the summer temperature ranges from 20°C to 33°C and in winter 15°C to 28°C. In Nariyampara the average temperature is 20°C. Summer temperatures range from 19°C to 29°C and winter temperatures are in the range of 15°C to 24°C. Average rainfall according to Centre for Earth Studies Resource Atlas of Kerala (1984) for South West Monsoon is 150 cm at Nariyampara and 250 cm at Nelliampathy. For both sites, Northeast Monsoon was 40 cm and ‘Other rains’ was reported as 30–50 cm.



FIGURE 10. Larval case a. male, b. female.

Biology. The larvae of this species were found scraping on the bark of trees, they seem to feed on the bark tissues and depositions (algae) on the bark. The pupal cases are attached by a thread to the branches and underside of the leaves of plants (Fig. 12).

The life span of an emerged male adult was up to 4 to 5 days. There are many eggs wrapped with silken cases were seen inside the female cases, and female adults lay eggs using their ovipositor inside the case after mating. Each yellow-coloured egg was found wrapped inside loosely spun silken cocoons. Eggs clustered together to form a group egg mass (Fig. 13) inside the sheath of the case. The larval case is made of silk and covered with bark tissues, and other substances present in the bark.

DNA barcode and phylogenetic analysis. COI sequencing of the species collected from the two locations Nariyampara and Nelliampathy was done and the sequences have 641 and 654 base pairs respectively. The sequences were uploaded in the NCBI GenBank with the accession numbers OP960232 and OP957497.

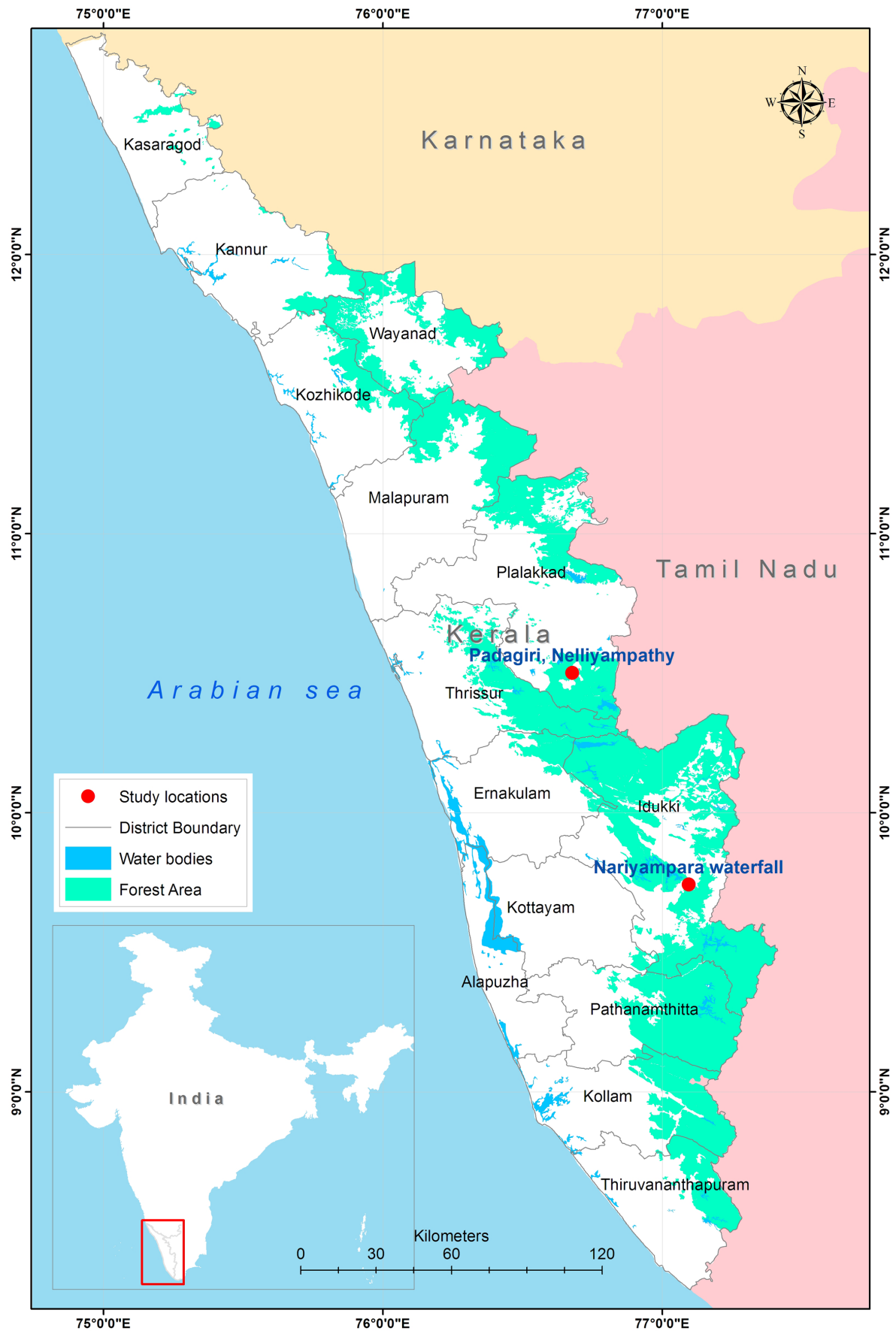


FIGURE 11. Map showing location of type locality

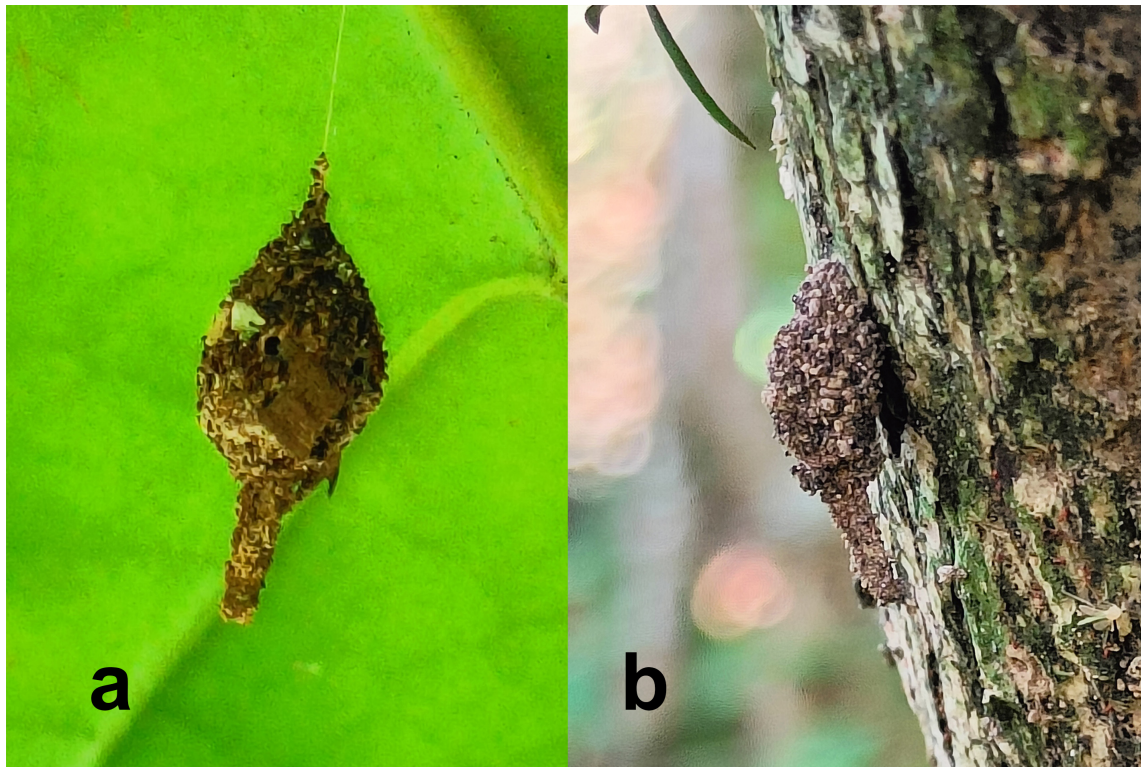


FIGURE 12. Larval habitat; a. Larval case attached to underside of a coffee leaf. b. Larval case seen on the bark of a coffee plant as larva feeds on moss.

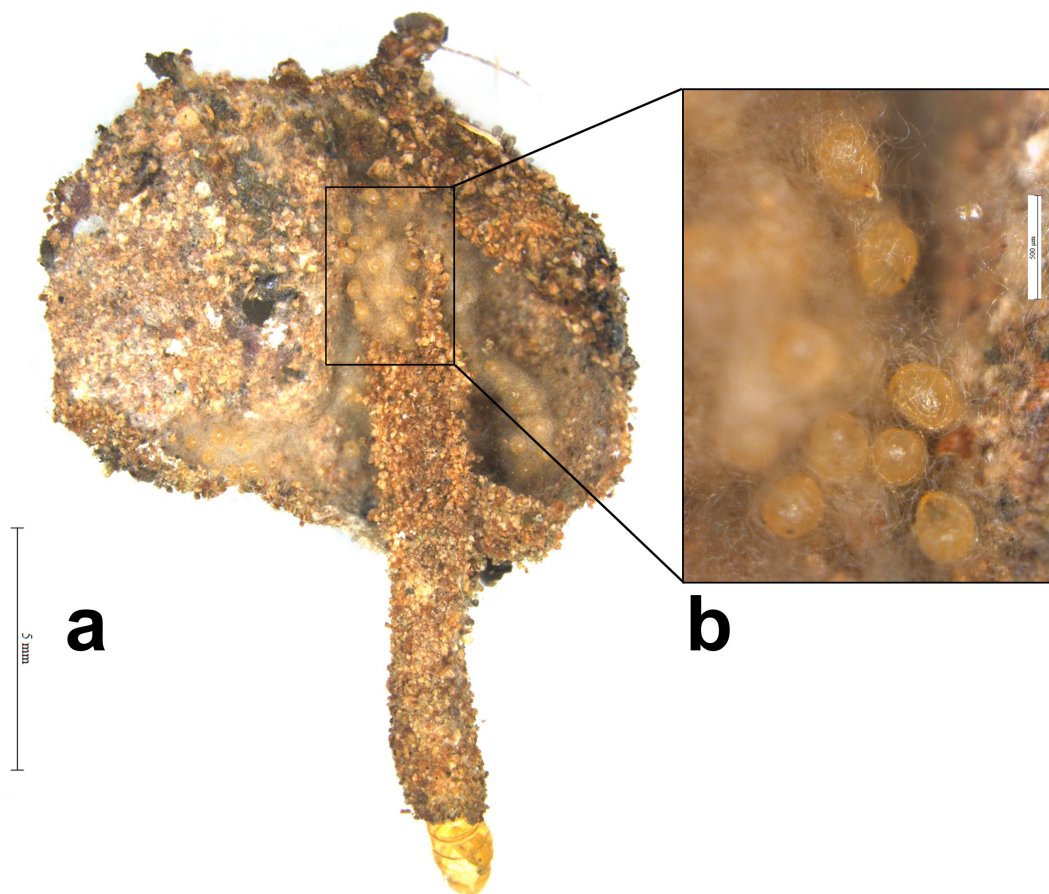


FIGURE 13. a. Egg masses in case with outer wall dissected and spread b: eggs wrapped in silk.

The evolutionary relationship is depicted in the tree with the highest log likelihood (-3908,46) (Fig. 14). Based on the tree constructed using these two COI genes and other available species from GenBank and BOLD SYSTEMS, a hypothetical taxonomic unit representing a Taleporiinae ancestor splits into two branches with three genera *Bankesia*, *Pseudobankesia*, and *Taleporia* forming one group and *Sciopetris melitensis* forming the second group with *Capulopsyche keralensis* **gen. et sp. nov.**. The distance between *S. melitensis* and *Capulopsyche keralensis* **gen. et sp. nov.** indicates that they are two distinct species. In addition *S. melitensis* is a Mediterranean palaearctic species.

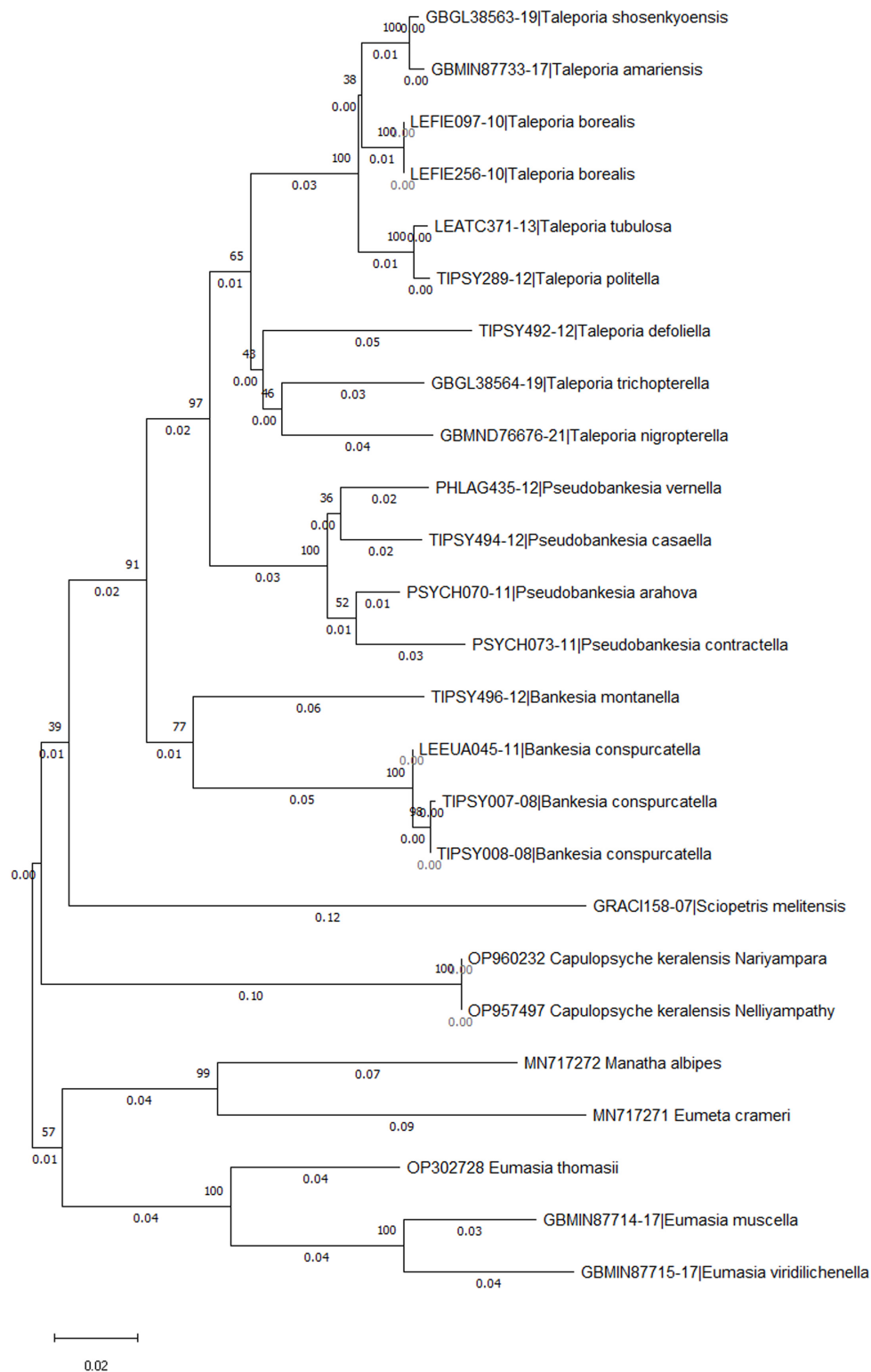


FIGURE 14. Phylogenetic tree of Taleporiinae with *Capulopsyche keralensis* **gen. et sp. nov.**

Discussion

Capulopsyche keralensis **gen. et sp. nov.** has a wingspan of only 8–8.4 mm and, therefore, is a very small representative of the subfamily Taleporiinae. Wingspan of more than 9 mm are typical in Taleporiini, mostly more than 10 mm. *Pseudobankesia macedoniella* (Rebel, 1920) (8.4–12 mm), *Pseudobankesia aphroditae* Weidlich & Henderickx, 2002 (8.5–10 mm) and *Pseudobankesia kresnensis* Weidlich 2014 (8.6–11 mm) come closest to the low values. They are all scaled much lighter and have a more or less pronounced reticular pattern. Other significant differences are in the veining (see diagnosis *Capulopsyche keralensis* **gen. et sp. nov.**).

Altobankesia cavernicola Dierl, 1966 from Nepal has a wingspan of 13.8–15.8 mm. The forewings are light brown with numerous yellowish-white spots. The larval cases are 7–9 mm long and between 2–3 mm wide which is significantly smaller than the larval cases of the new species (length 12–16 mm, width 5–7 mm). Double-walled larval cases reported from Psychidae are the triangular larval cases of *Diplodoma* Zeller, 1852 which also hung up on threads. But in *Diplodoma*, the inner case has a distinctive triangular shape and is not visible from the outside. The outer case also has a triangular basic shape in cross-section.

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Eumasia thomasii sp. nov. a new species of the subfamily Eumasiinae (Lepidoptera: Psychidae) from India

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Abstract

A new species of bagworm, *Eumasia thomasii* sp. nov. is described from Kerala, India. This is the third species in the genus *Eumasia* reported from India and the tenth from Asia. The report presents the morphology of adults, larva, and cases along with information on distribution and ecology.

Key words: Bagworm, *Eumasia*, Kerala, India, COI

Introduction

The family Psychidae consist of small to medium-sized moths which build cases around their bodies during larval stages (Rhainds *et al.* 2008). Known as bagworms, there are 241 genera and 1450 species worldwide (Sobczyk 2011, 2019; Nieuwerkerken *et al.* 2011). Arnscheid & Weidlich defined the Eumasiinae subfamily in the Psychidae in 2017, based on the monotype genus *Eumasia* Chretien 1904. Fourteen species of *Eumasia* have been identified worldwide (Sobczyk 2011, 2015; Arnscheid and Weidlich 2017) of which eight species are from the Palaearctic and six species are from the Oriental region (Sobczyk 2011, 2015; Arnscheid & Weidlich 2017, Roh *et al.* 2018). Nine species are reported from Asian countries (Table 3), of which two are from India (Sobczyk 2011), namely—*Eumasia arenatella* (Walker, 1864): Sri Lanka, India, and *Eumasia exoria* Meyrick, 1919: India (Bengal, Pusa).

During field visits to Vattavada in January and June 2022, several pupal cases with a unique shape were observed. Cases were collected and observed in the laboratory. Hatched adults presented all characteristics of the adult of Eumasiinae: Wings are developed in both sexes; antennae filiform and each segment of male antennae covered with short cilia and middle segment with dorsally fanned scales forewing lanceolate and narrow with mostly seven veins arising from dc; sacculus of male genitalia blunt; annellus lacked and the juxta like wide plate (Saigusa & Sugimoto 2005; Arnscheid & Weidlich 2017; Roh *et al.* 2018). Further comparison with other species of *Eumasia* confirmed that it is a hitherto undescribed species. This paper illustrates the detailed morphology of adults, pupa, larvae, and larval cases of the new species. A maximum likelihood phylogeny of the mitochondrial COI gene is also presented, along with the GenBank accession number.

Materials and methods

154 pupal cases were collected from Vattavada, Idukki district of Kerala. Hatched and unhatched cases were sorted. The unhatched pupal cases were kept inside rearing bottles at room temperature until the emergence of adult insects. The emerged moths were used for further studies. Wing colouration, markings and arrangement of

scales were studied before the slide preparations. Wing venation was examined by preparing microscopic slides. Wings were kept in absolute alcohol for descaling, treated with fuchsin stain and mounted in Canada balsam. Male genitalia were dissected and examined after mounting in alcohol and then preserved in Canada balsam. The terminology of the external morphology of adults and male genitalia follows Sauter (1956). Photographs and measurements of the specimens were taken using DFC450 camera of Leica M205C stereomicroscope and Leica S8APO stereomicroscope.

COI Gene Sequencing: DNA was extracted from the thoracic region of the male moth. Sequencing of the cytochrome oxidase I gene of the species was done at the RGCB, Trivandrum, using the forward and reverse primers LCO and HCO respectively (Folmer *et al.* 1994) (Table 1). Using Geneious Prime, the forward and reverse sequence reads were assembled following Drummond *et al.* (2010). The evolutionary relationships were inferred by using the Maximum Likelihood method and General Time Reversible model (Nei & Kumar, 2000). The percentage of trees in which the associated taxa clustered together is shown next to the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbour-Joining and BioNJ algorithms to a matrix of pairwise distances estimated using the Maximum Composite Likelihood (MCL) approach, and then selecting the topology with superior log likelihood value. The tree is drawn to scale, with branch lengths measured in the number of substitutions per site (next to the branches). This analysis involved 11 nucleotide sequences of which 10 sequences were retrieved from NCBI GenBank. Two outgroup taxa from a related psychid subfamily, Oiketinae, were included (*Manatha albipes* and *Eumeta crameri*; Table 2). Codon positions included were 1st+2nd+3rd+Noncoding. There was a total of 692 positions in the final dataset. Evolutionary analyses were conducted in MEGA11 (Tamura *et al.* 2021).

TABLE 1. Details of primers used in sequencing at RGCB, Trivandrum

Primer Name	Direction	Sequence (5' → 3')	Target
LCO	Forward	GGTCAACAAATCATAAAGATATTGG	COI
HCO	Reverse	TAAACTTCAGGGTGACCAAAAAATCA	

TABLE 2. COI Sequence details of Phylogenetic analysis

Sl No	Accession number	Species	Country	Authors	Base pair length
1	JN299400	<i>Eumasia parietariella</i>	Slovenia	Unpublished	658
2	JN307737	<i>Eumasia parietariella</i>	Spain	Unpublished	658
3	KU497353	<i>Eumasia parietariella</i>	Italy	Scalercio, S., Bonacci, T., Turco, R. and Bernardini, V., 2016. Unpublished	658
4	LC094211	<i>Eumasia muscella</i>	Japan	Sugawara, H. and Hayashi, F.	665
5	LC094210	<i>Eumasia muscella</i>	Japan	2015	665
6	LC094205	<i>Eumasia muscella</i>	Japan	Unpublished	662
7	LC094199	<i>Eumasia viridilichenella</i>	Japan		665
8	LC094198	<i>Eumasia viridilichenella</i>	Japan		665
9	OP302728	<i>Eumasia thomasii</i>	India		687
10	MN717272	<i>Manatha albipes</i>	India	Usha, A.U., Sobczyk, T., Roby, T.J. and Jose, J. 2022	692
11	MN717271	<i>Eumeta crameri</i>	India	Usha, A.U. and Jose, J. 2019	689

Abbreviations

RGCB	Rajiv Gandhi Centre for Biotechnology, Trivandrum
NCBI	National Centre for Biotechnology Information, Bethesda, Maryland, USA
BLAST	Basic Local Alignment Search Tool
EI	Eye-Index (Smallest eye distance / vertical eye diameter in anterior view)
WI	Forewing-Index (maximum length base to apex divided by the maximum width)
mASL	metres Above Sea Level

Taxonomic part

Order Lepidoptera Linnaeus, 1758

Family Psychidae Boisduval, 1829

Subfamily Eumasiinae Arnscheid & Weidlich, 2017

Genus *Eumasia* Chrétien, 1904

Eumasia Chrétien, 1904: 120. Type species: *Coleophora parietariella* (Heydenreich, 1851)

Eumasia thomasii sp. nov.

(Figs 1–11)

Type material. Holotype. ♂, INDIA, Kerala, Vattavada, Koviloor, 10.18211° N, 77.25923°, 11/07/2022, with larval case, leg. Usha A U. Holotype will be deposited at the Zoological Survey of India Museum, Calicut, Kerala after submission of thesis of the first author and is at present at St. Thomas College, Thrissur.

Paratypes: 2 females (both with larval case), same data as holotype, 10/07/2022, 25 larval cases with pupal exuviae, leg. Usha A U.

Etymology. The adult female in most bagworm species is characterized by rudimentary appendages and eyes and no wings. But in this species both male and female are winged, have well developed eyes, legs, and antennae. Therefore; the male and female adult moths are almost twin like. The word Thomas means ‘twin’ in aramic. The institution “St. Thomas College” in which the major part of the research was carried out is named for St. Thomas. Hence the species name “*thomasii*” alludes to the similar appearance of males and females and is also a homage to the institution.

Description. Holotype ♂ (Fig. 1), wingspan 8–8.3 mm, body length 2.5–3 mm, forewing length 4.1 mm including fringes, width 1.1 mm, WI 3.7 mm.



FIGURE 1. ♂ Holotype of *Eumasia thomasii* sps. nov. currently at STC, Thrissur India

Head. Vertex roughly covered with pale golden-brown hairs. Eyes large, inter ocular index, EI 1.2 mm. Antenna short, filiform, 1.7 mm long, and 25 segments (Fig. 2a). Segments sparsely ciliated, especially ventrally, dorsally with a fan-shaped process of dark brown scales, angle about 35° (according to Hättenschwiler 1998).

Thorax. Densely covered with long brown scales. Forewing (Fig. 3a) narrow and lanceolate, costa straight and termen tapering at apex. Discoidal cell is half the length of the forewing. Median stem of dc complete but faded from middle to apex dc. Dc bordered externally with transverse veins (not open, as in most *Eumasia* species). Venation: forewing with nine veins, seven veins from the dc. Sc straight and ended up in the middle length of costa. R1 from dc is parallel to the vein Sc but originating different length from the base. R2+3 and R4+5 run parallelly and end up on the costal margin at different lengths. M1 and R4+5 originate apically from dc reaching to apex. Veins R4+5 and M1 are not stalked at base but originate from the same point on the apex of dc. Veins M2+3, CuA1 and CuA2 are short and parallel to each other.

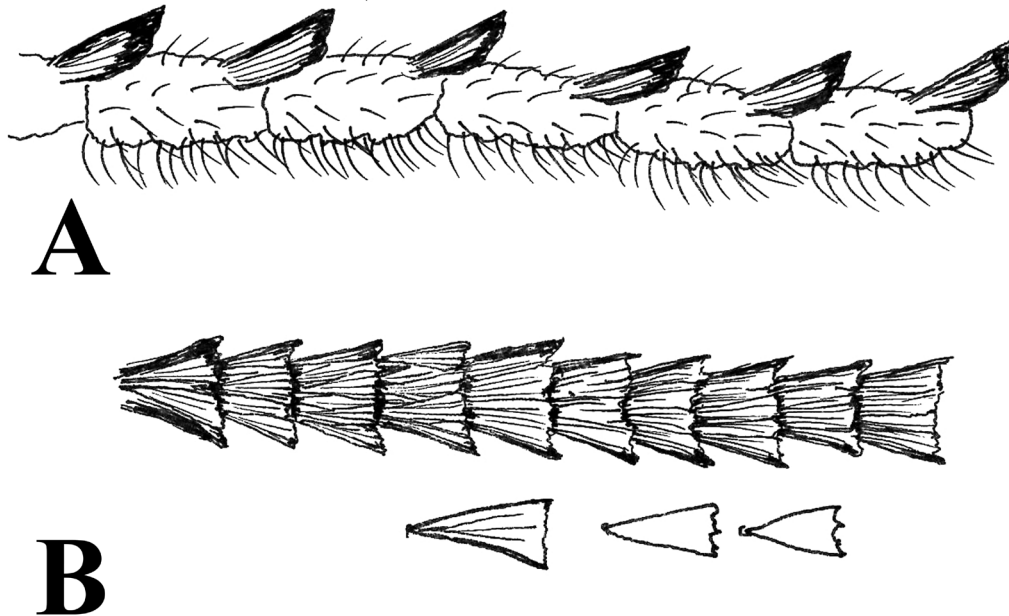


FIGURE 2. Antennae a. male, b. female, drawing T. Sobczyk

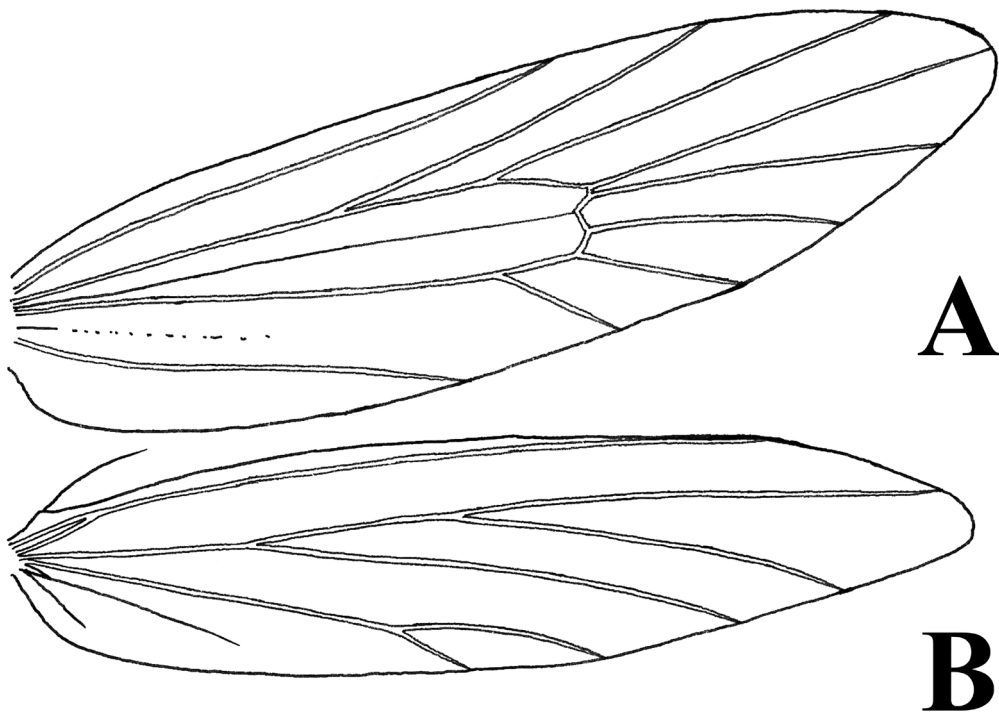


FIGURE 3. a. Female forewing, b. hindwing, drawing T. Sobczyk

Hindwing (Fig. 3b) is narrow and small, costa straight and vein Sc+R1 run adjacent to costa. Vein Rs and M1 are stalked and terminating to apex and termen respectively. M1 and M2+M3 run parallelly to termen. CuA1 and CuA2 are stalked and short. Anal veins are very short and almost invisible on the wings. Forewings thickly covered with broad, mostly 5–6 pointed scales (Fig. 4a) (classes 5–6 after Sauter 1956). Ground colour of the upper side of the forewing is greyish white marked with blackish brown spots. Anterior margin without clear dark spots. An indistinct oblique band of dark scales from one-fourth of the anterior margin to half of the posterior margin. Another band from half anterior margin to half posterior margin. A third band slightly distal to it. A most conspicuous feature is a broad band of dark scales at three-quarters wing length. Distal to this, isolated dark scales towards the apex and outer margin. Fringes whitish, narrow, unicoloured, usually 3-pointed distally (Fig. 4b).

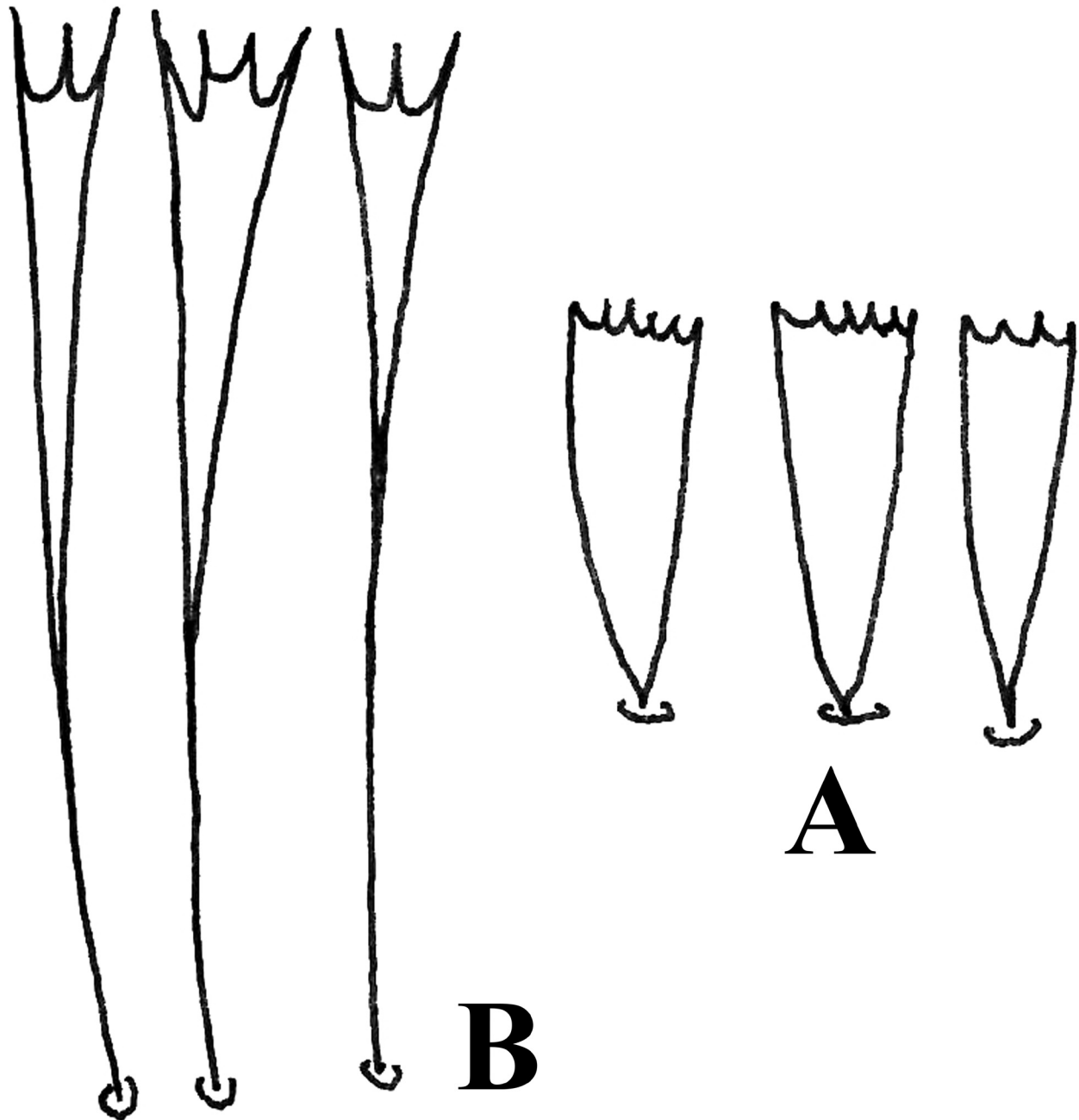


FIGURE 4. Forewing a. scales b. fringes, drawing T. Sobczyk

Hindwing ground colour silver white without any spots and markings, covered with white greyish coloured scales. Scales narrower as fore wing, more rounded distally, few indentations. Outer margin with long whitish fringes. Forelegs (Fig. 5) ventrally with long hairbrush along with the length of tibia, hind legs are very long, 4.5 mm in length, covered with long whitish hairs on tibia and shorter hairlike scales on tarsal segments.



FIGURE 5. ♂ Foreleg

Abdomen. Abdomen long, thickly covered with blackish brown scales.

Genitalia (Fig. 6). 0.86 mm long, Tegumen arched anteriorly and concave Valva elongate and symmetrical, presence of hairs anteriorly. Vinculum V shaped and saccus very long and pointed at apex. Saccus two-thirds the length of the genitalia. Phallus very long and straight tube-like structure, with pointed tip, length 0.52 mm.

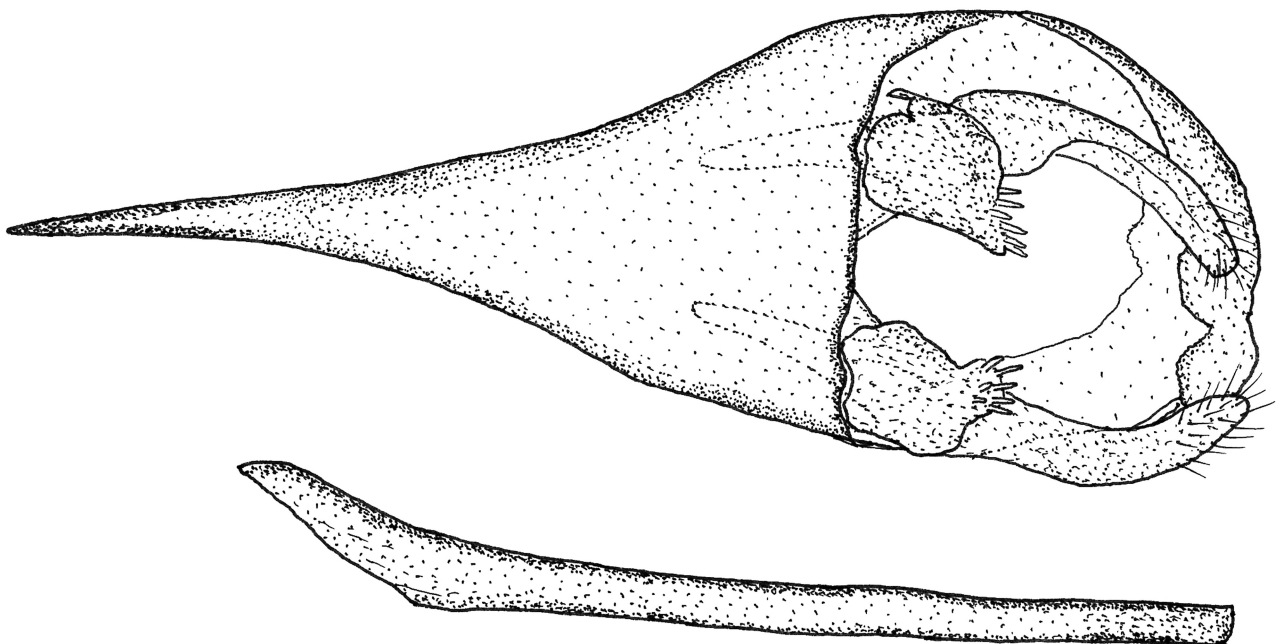


FIGURE 6. ♂ Male genital, drawing T. Sobczyk

Paratype ♀ (Fig. 7). Winged; Body 3.5–4.2 mm long, stout and larger than males; wingspan 8–8.8 mm including fringes, sizes of the wings of female and male are same, forewing length including fringes 4.1 mm, width 1.1 mm, forewing index 3.7 mm. Vertex is covered with thick pale golden coloured hairlike scales, antennae (Fig. 2b) filiform, 23–25 segments, length 1.6 mm, completely covered with broad scales arranged in rings, slightly projecting distally, without cilia. Thorax is pale brown, sparsely covered with scales. Abdomen long, stout, pale-

yellow, 3 mm long, white greyish scales on the abdominal segments and golden coloured hair tuft on the last abdominal segment. Forewing thickly covered with light brown and blackish scales; blackish scales are arranged as spots on the forewings. Hindwings are without markings and patterns, densely covered with white greyish scales, outer margins of both the wings are with long fringes.



FIGURE 7. ♀ Paratype of *Eumasia thomasii* **sp. nov.** currently at STC Thrissur India

Pupal exuvia (Fig. 8). Pupal cases of both the sexes light brown coloured. Length of a male pupal case 2.6 mm, width 0.8 mm, in female 3.6 mm and width 1.0 mm.

Larva (Fig. 9). Mature larva 3–3.5 mm long, head dark brown, thoracic segments pale brown, more strongly sclerotized, without clearly separated darker fields. Abdomen pale yellow. Thoracic legs are well developed and blackish brown. Anal prolegs are very short.

Larval case (Fig. 10a and b). Cases of this species are round externally with a long tube protruding at the lower end. The tube extends upward internally as long tube-like case of width 1.5 mm, it is wrapped with a sheath made up of silk, sand, soil particles, snail shells, algae, and insect debris. All the cases were found attached to the underside of the rocks with a small thread (Fig. 11). Male larval cases are smaller than females and it have 8.5–11 mm total length and 3.5–5 mm width at middle, female larval cases are 11.5–13 mm long and 4.5–6 mm wide.

Location. The pupal cases were collected from Koviloor (10.18211°N and 77.25923° E), Vattavada, Idukki district, Kerala. Koviloor is a mixed culture village, situated in Vattavada Panchayat. It is 43.5 kms from Munnar on the road to Kodaikanal (Fig. 12). Altitude at the place of collection was 1700m (5577.42 feet) ASL. Koviloor is surrounded by different hill peaks such as Pattitaichchi mala (2497 mASL), Kaladankanava mettu (2457 mASL), Pullardi shola reserved forest, Jhanda mala (2522 mASL) and Vattavada (2153 mASL). The soil type of the region is described as ‘Clayey mixed ustic pale humults and rock land (very deep, well drained, clayey soil on moderately steeply sloping high hills with thin vegetation, with moderate erosion, associated with rock outcrops) in Soil Maps of India (1996). In Vattavada the winter temperature ranges from 5 °C to 20 °C and in summer 12 °C to 18 °C, in monsoon season, maximum daily temperature is very low and highest temperature recorded is 19 °C. Average rainfall according to Centre for Earth Studies Resource Atlas of Kerala (1984) is North east Monsoon– 50–60 cm; South west 150–200 cm and other rains 30–40 cm.

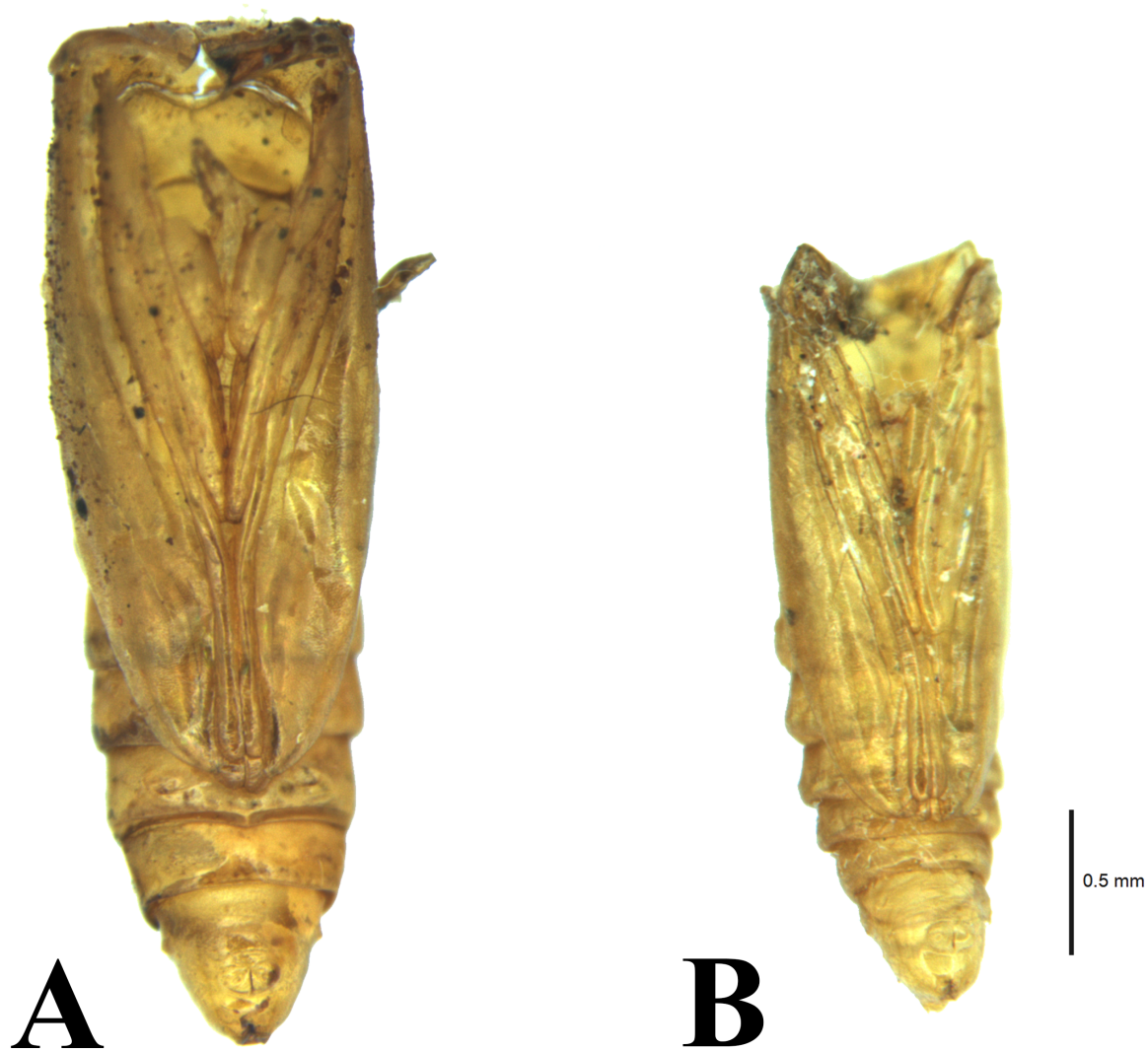


FIGURE 8. Pupal exuvia a. female b. male



FIGURE 9. Larva

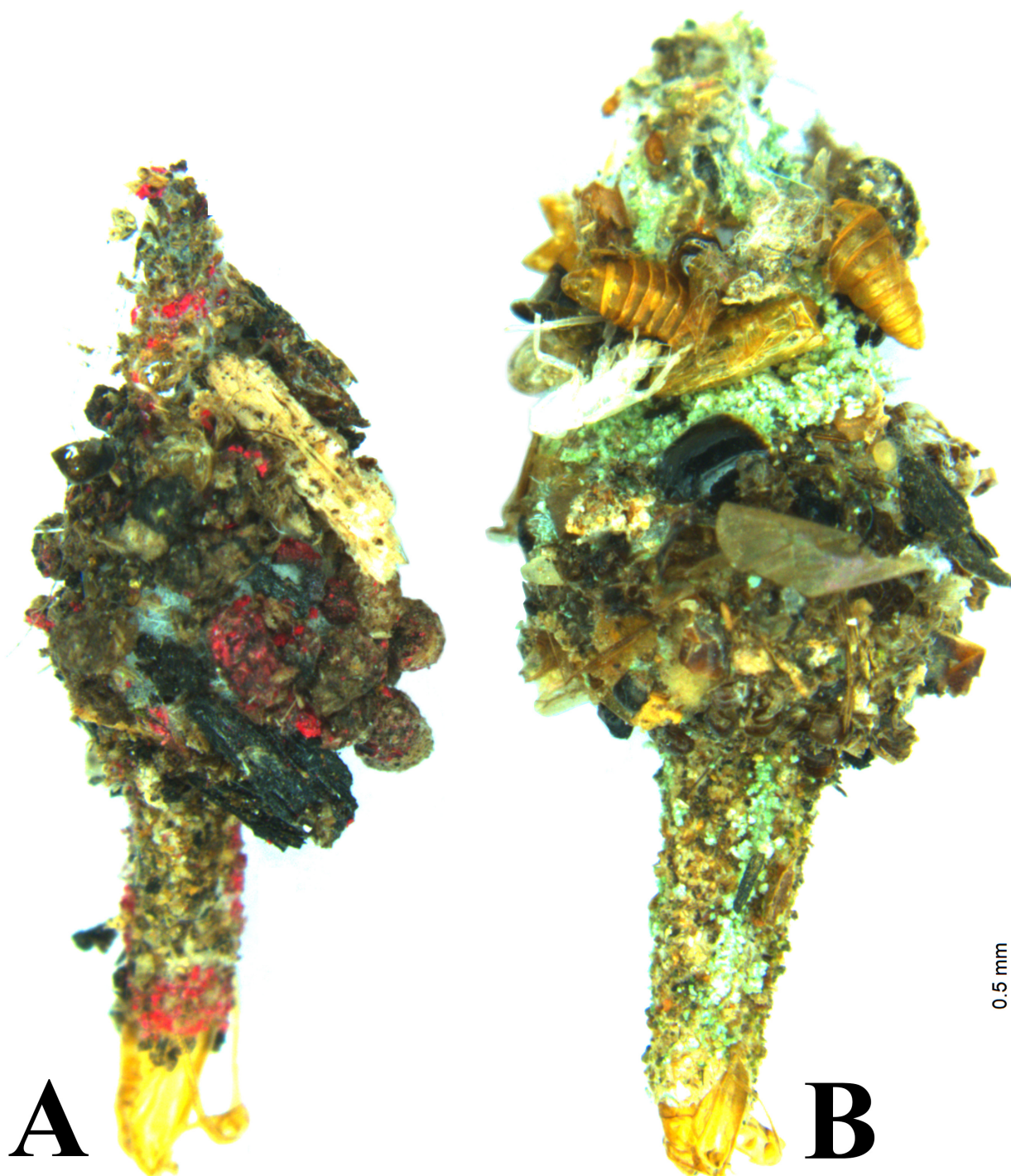


FIGURE 10. Larval case a. male, b. female

Biology. The larval cases were collected from underside of rocks. Active larvae were observed scrapping the surface of the rocks and it is assumed that the larvae fed on the algae and mosses on the rocks following previous reports (Saigusa and Sugimoto 2013; Roh and Byun 2016, Roh *et al.* 2018). Bits of algae and mosses were retrieved from the larval cases. Adult emergence was noted at night. Male moths are active flyers after emergence, they are active during day and night, whereas females moved less and stay on the case and its vicinity after emergence. It is assumed that the larger size and weight of their abdomen is a restraint to flight. Distinguishing the moths and cases from the surroundings are difficult due to its colour and positioning of cases, a characteristic suitable to evade from predators. The duration of pupation was 15–18 days. Life span of females was one week, whereas male adults lived up to 3–4 days.



FIGURE 11. Larval habitat

DNA barcode and phylogeny. COI sequencing of the species was done and the sequence has 687 base pairs. The sequence was uploaded in the NCBI GenBank with the accession number OP302728. The BLAST search results of the sequence show 91.03% sequence similarity with *Eumasia parietariella* (KX045802) from Germany and 90.83% with *Eumasia muscella* (LC094210) from Japan.

The evolutionary relationship is depicted in the tree with the highest log likelihood (-2328.62) (Fig.13). A hypothetical taxonomic unit of *Eumasia* ancestor split into two branches. *E. thomasi* **sp. nov.** shows affinity to the branch having *E. muscella* and *E. viridilichenella* but seems to have evolved earlier into an independent taxon. *E. parietariella* belongs to the other branch. Hättenschwiler (1998) separates *Eumasia* into an eastern and a western group based on morphological characteristics (e.g., epiphysis on the front leg tibia, length of saccus in relation to total length of male genitalia, lobes at tegumen on male genitalia). The eastern species show an epiphysis that is absent in the western species. According to this, *E. thomasi* **sp. nov.** would belong more to the western group (with *E. communita* and *E. parietariella*), in contrast to *E. muscella* and *E. viridilichenella*. The pronounced saccus and lobular processes of the tegumen, on the other hand, correspond to the eastern group. It seems that this division into regional groups is not consistent.

Diagnosis. *Eumasia thomasi* **sp. nov.** differs from *E. muscella* (Saigusa & Sugimoto, 2005, Roh *et al.* 2018) from Japan and South Korea by forewing venation -, the veins R4+5 and M1, M2+3 and CuA1 are stalked in *E. muscella*, whereas no veins are stalked in *E. thomasi* **sp. nov.**

With regards to the difference between *E. zieglerei* and other *Eumasia*, Hättenschwiler (1998) writes: “The species *E. parvulella* (Walker, 1863) and *E. arenatella* (Walker, 1864) described from Southeast Asia are larger; the latter has 8 (or 6 veins from the dc), *E. testata* (Meyrick, 1911) is also larger [as *E. zieglerei*], has whitish hind wings and flies March to April; *E. crypsiphila* Meyrick, 1919 from Sri Lanka has a similar habit but flies as early as January and *E. exoria* Meyrick, 1919 from Pusa, Bengal in northern India has white-grey hind wings and is larger.” For all these species, the original descriptions say little, they are often based on individual specimens and do not allow statements about the variation.

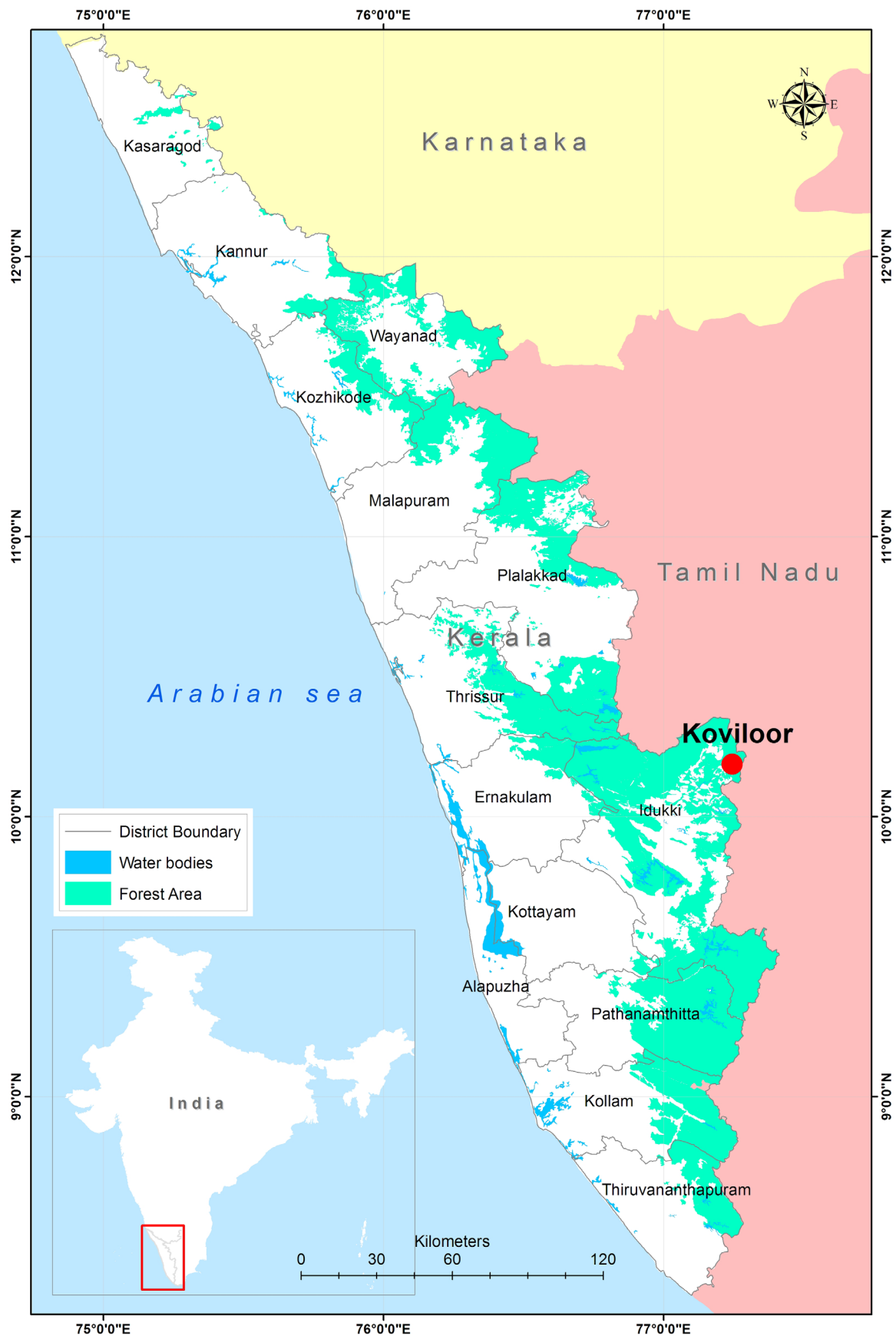


FIGURE 12. Map of type locality

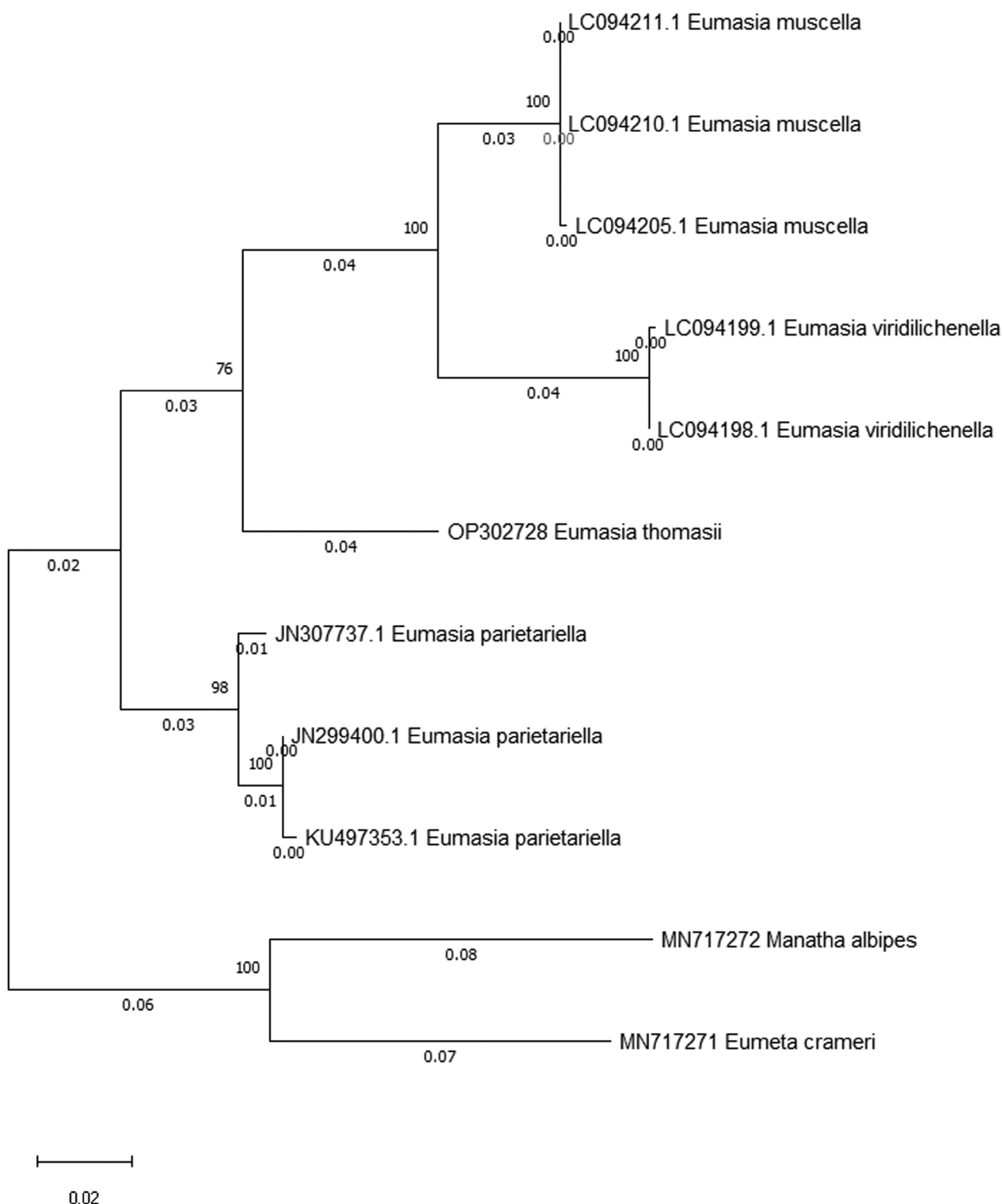


FIGURE 13. Phylogenetic tree of *Eumasia*

Only two species are reported from India: *E. exoria* and *E. arenatella*. For *E. arenatella*, the first record from India at Kurseong, E. Himalayas, 5000 ft., in the month of September was added by Meyrick (1910) with no further information on specimen numbers or appearance: The original description by Walker gives a wingspan of 12.6 mm for the female of *E. arenatella*. It is thus significantly larger than *E. thomasi* **sp. nov.** *E. arenatella* has only six veins from the forewing dc (Hättenschwiler 1998) but in *E. thomasi* **sp. nov.** there are seven. The flight time of *E. arenatella* is reported as in March, April, and September. Flight was observed in *E. thomasi* during January and July. *E. exoria*, known from the holotype male is more similar to *E. thomasi*. The wingspan is slightly larger than

that of *E. thomasi* **sp. nov.** (9 mm vs. 8.0–8.8mm). *E. exoria* flies later (September). The species is clearly paler. Head and thorax are ochreous-whitish (*E. thomasi* **sp. nov.**: head golden-brown, thorax brown). The forewings of *E. exoria* are clearly paler and the markings stand out prominently: “*markings dark fuscous; five roundish spots on costa, two in the disc at middle and $\frac{3}{4}$ (representing stigmata), and several small elongate marks on posterior part of dorsum and termen. Cilia whitish, basal half barred dark fuscous irroration.*” (Meyrick 1919). From the middle of the posterior edge, a line sharply defined on the inside runs parallel to the outer edge towards the apex. The bright field between dc and apex of the forewings is striking (in *E. thomasi* **sp. nov.** with dark brown scales, hardly lightened). At 1/3 of the forewing, *E. thomasi* **sp. nov.** a slanting, dark band of scales from anterior to posterior edge. In *E. exoria*, the basal half of the wing is clearly brighter and almost without markings. An overview of the Asian species (Table 3) summarizes the differences of these species from *E. thomasi* **sp. nov.** based on available information.

TABLE 3. Overview of species in the genus *Eumasia* in Asia (M: male, F: female)

Eumasia	Distribution	Wingspan (mm)	Length larval case (mm)	Veins from forewing dc	Colour hindwing	Flight time (month)
<i>thomasi</i> sp. nov.	India, Kerala	M: 8–8.3 F: 8–8.8	M: 8.5–11 F: 11.5–13	7	white greyish	1,7
<i>arenatella</i> (Walker, 1864)	Sri Lanka (“Ceylon”), India, Darjiling	M: unknown F: 12,7 (6 lines)	unknown	6	white	3–4 and 9
<i>cryptiphila</i> Meyrick, 1919	Sri Lanka (“Ceylon, Galle)	M: 7–9 F: 7–9	unknown	?	dark grey	1
<i>exoria</i> Meyrick, 1919	India, Bengal, Pusa	M: 9 F: unknown	unknown	?	whitish-grey	9
<i>muscella</i> Saigusa & Sugimoto, 2005	Japan, Honshu, Kyushu	M: 9.1–10.2 F: 9.5–11.3	M/F: 8.5–9.5	7	pale yellow white	7
<i>parvulella</i> Walker, 1863	Sri Lanka (“Ceylon”)	M: 7,4 (3,5 lines) F: unknown	unknown	?	pale grey (?)	?
<i>testata</i> Meyrick, 1911	Sri Lanka (“Ceylon, Peradeniya and Madulsima”)	M: 9.5–10.5 F: 11–12.5	M: 10.5–11 F: 11–16	?	pale grey	3
<i>viridilichenella</i> Saigusa & Sugimoto, 2005	Japan, Honshu, Kyushu	M: 8.2–10.1 F: 8.5–10.2 mm	M/F: 8–9	7	dark grey	6–7
<i>ziegleri</i> Hättenschwiler, 1998	Maldives, North-Male-Atoll	M: 5,5–7,5 (Mittel 5,7) F: 7–8	M: 5.5–6.5 F: 6.5–7.5	7	brown	6
<i>montanella</i> Solyanikov, 1986	Tajikistan	10–10.8	9–12	7	grey	6

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<https://doi.org/10.11646/zootaxa.3148.1.39>

Neotype designation, redescription, biology and distribution of *Acanthopsyche alstoni* Watt & Mann, 1903 (Lepidoptera: Psychidae) from India

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Abstract

Acanthopsyche alstoni Watt & Mann, is a lesser known psychid previously known only from the description of its larval cases collected from Assam, India in 1903. There were no descriptions of the adult moth or biology of the species. During surveys for Psychidae in the human inhabited regions of Kerala State, India, more than 100 larval cases were recovered. They were allowed to hatch and characteristics were recorded. This paper provides a detailed redescription of this species and designation of a neotype.

Key words: *Acanthopsyche*, distribution, Psychidae, redescription, rediscovery

Introduction

There are more than fifty species of *Acanthopsyche* reported globally of which six are from India (Sobczyk 2011). Watt & Mann (1903) described *Acanthopsyche alstoni* only from the larval cases of the species from Assam State in India. They reported some damage caused to plants by feeding but were not able to make any further description of the species. While *A. alstoni* has been listed in the checklist of Psychidae from India (Shah *et al.* 2015) there are no descriptions, illustrations or photographs of the species.

Acanthopsyche alstoni is reported from Kerala, India and also provided is a detailed description of the previously unknown adults of this species along with its distribution and details of host plants.

Indices and abbreviations

Following indices/abbreviations are used in this paper:

FI Forewing index (maximum width of the wings divided by the maximum length of forewing)

EI Eye index (smallest eye distance divided by the vertical eye diameter)

EPI Epiphysis index

dc discal cell

Materials and method

Many larval cases were serendipitously noted and 165 cases were collected from Wayanad, Idukki and Ernakulam districts of Kerala during surveys for Psychidae during October 2021 to January 2022. The collected larval and pu-

pal cases were sorted into small groups and kept in rearing bottles. Bottles with larval cases were provided twigs and leaves of the plant from which it was collected. Temperature and humidity were not specially regulated. Emergence of adults was noted. Adults are used for the morphological studies. Microscopic slides of wing venation, genitalia, and legs were prepared by standard protocols (Robinson 1976, Kunte 2000), genitalia characters were studied in their natural position before embedding in Canada balsam. Photographs were taken using Leica stereomicroscope S8APO. Photographs were resized to meet journal specification in Adobe Photoshop.

Distribution map and host plants: A distribution map of *Acanthopsyche alstoni* was created in QGIS by plotting the geo-coordinates of the species occurrences in the observed area. Host plants were recorded at the time of collection and tabulated.

DNA barcoding: DNA was isolated from the moth and sequenced at the Rajiv Gandhi Centre for Biotechnology (RGCB), Trivandrum. The sequence quality was checked using Sequence Scanner Software v1 (Applied Biosystems). Sequence alignment and required editing of the obtained sequences were carried out using Geneious Pro v5.1 (Drummond *et al.* 2010).

Taxonomy

Acanthopsyche Heylaerts, 1881

Acanthopsyche Heylaerts, 1881, *Annales de la Société entomologique de Belgique*, 25: 66 (key), 70.

Type species: *Psyche opacella* Herrich-Schäffer, 1846: 20, by subsequent designation by Tutt (1900: 378).

Psychidae: Oiketicinae: Acanthopsychini (Sauter & Hättenschwiler 1991: 84), *Acanthopsyche alstoni* Watt & Mann, 1903

Acanthopsyche is characterized by males with bipectinated antenna and long ciliated pecten. Forewings with nine veins from dc and narrow scales. Hindwings with five veins from dc. Intercalary cell and accessory cell absent. Forelegs with long epiphysis, midleg and hindleg without spurs. Female apterous, eyes, antenna and legs rudimentary. Thoracic segments sclerotized dorsally (Hampson 1892).

***Acanthopsyche alstoni* Watt & Mann, 1903:** 197, nr. 28, type specimens (unknown numbers of larval cases) lost (Sobczyk 2011).

Type locality: India, “Duars”. The original description of *A. alstoni* Watt & Mann, 1903 is restricted to the larval cases.

Neotype examined: ♂. The Neotype is labelled as follows: 1) INDIA, Kerala, Athani, Ernakulam, (10.155517N and 76.354428 E) day of emergence, 13-11-2021, male 2) (supplementary specimen) *Acanthopsyche alstoni*, day of emergence 01-12-2021, female.

At present, the neotype are kept at the museum of the Department of Zoology, St. Thomas College, Thrissur as the work is a part of the doctoral degree of the first author. Once the thesis is submitted, the specimens will be transferred to Zoological Survey of India, India.

Material examined: INDIA, Kerala, Athani, Ernakulam (10.155517 N and 76.354428 E), altitude (15 mASL) 16 larval cases, Athani (Ernakulam); 23 larval cases, Cheruthoni, Idukki; 1 larval case, Anchuruli, Idukki; 3 larval cases, Nariyampara, Idukki (all collected during 03-10-2021 to 05-01-2022. Usha).

Supplementary description: ♂ (Fig. 1a,b): Relatively small species with brownish black and thick scaled wings. Body length 2.5–3 mm, Wingspan 7.4 mm, forewing length 3.2 mm, forewing width 1.6 mm, forewing index 0.5 mm.

Head. Covered densely with long brownish scales. Eyes medium-sized, black, interocular index 1.4 mm. Labial palpi fused. Tentorial pits and tentorium clearly pronounced. Antennae (Fig. 2): 12 segments, antennae length 1.35 mm, segments bipectinated, to apex uniformly decreasing, with cilia on the both sides. On the third and fourth antennal segment reaching maximum length, Scapus thickened, pedicellus disc-shaped.

Thorax. Forelegs covered with brownish hairs and tibia with epiphysis (EPI: 0.64 mm). Distal tarsal segment slightly longer than other tarsal segments. Thorax measures 1.1 mm and with long brownish hairs. Abdomen is long 1.4 mm, covered with brown hair like scales. Wings over side thick scaled brownish black, without pattern, underside of both wings are with brownish scales (Fig. 3a,b).

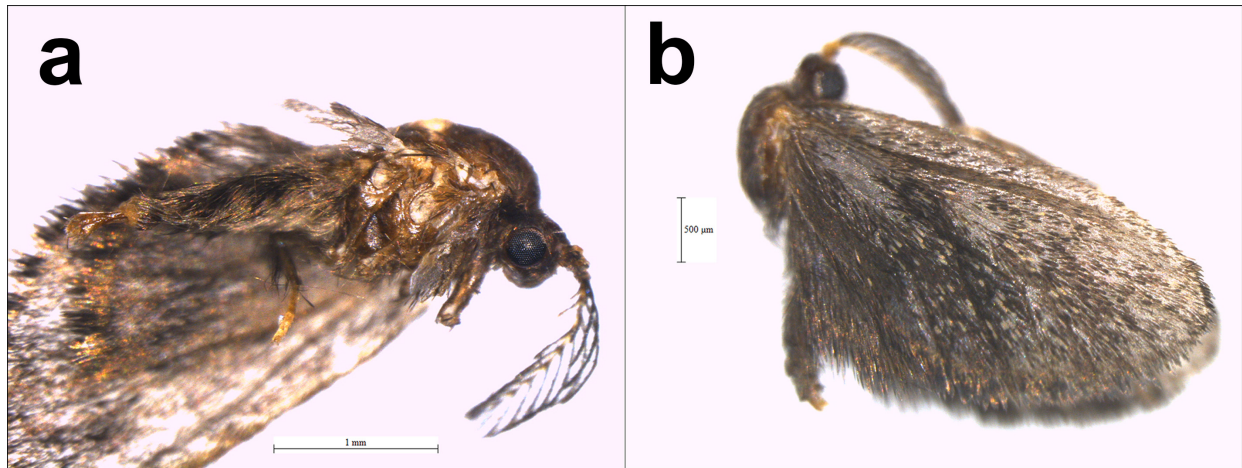


FIGURE 1a: ♂ Neotype of *Acanthopsyche alstoni* currently at STC Thrissur India—magnified view of head and thorax; **b:** ♂ Neotype of *Acanthopsyche alstoni* at STC Thrissur India—full body view.



FIGURE 2: ♂ Antenna (detached)

Wing venation (Fig. 4a,b,c): Nine veins from dc forewing. In dc media stem undivided, dividing the cell into a larger anterior part and a small posterior part, without accessory cell. Sc runs parallel to the R veins to the apex. Median stem run in outer margin dc between M1 and M2. From dc edge R3+R4 to one half stalked, with R2 short stalked or from a point. The three M-veins are free. Two Cu veins are present and originate distally from dc. Basal fork of anal veins A1 and A2 are prominent. Hind wings with five veins from dc, this nearby M2+M3 distally expanded. Median stem undivided. Sc free ends in front of apex at anterior margin. R1 at half its length with connecting bridge to dc. Three anal veins are free.

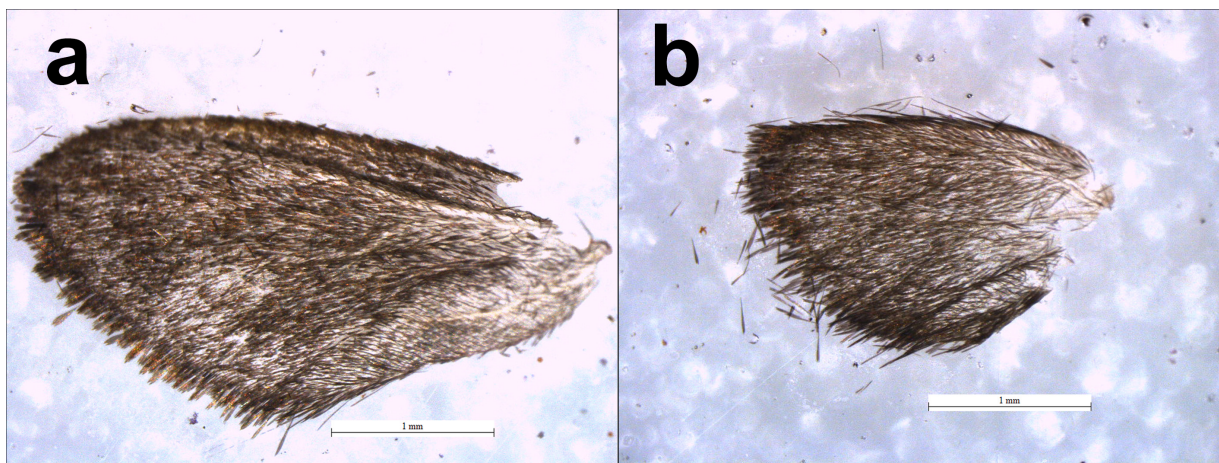


FIGURE 3a: ♂ Forewing; **b:** ♂ Hind wing.

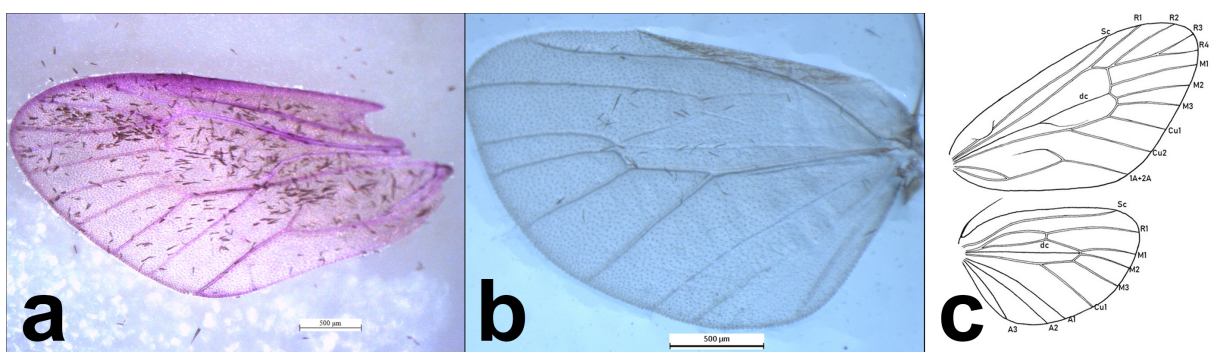


FIGURE 4a: ♂ Fore Wing venation, descaled, coloured in Fuchsin, mounted in alcohol; **b:** ♂ Hindwing Wing, descaled, coloured in Fuchsin, mounted in alcohol; **4c:** Wing venation.

Abdomen. Genitalia (Fig. 5): Elongated, 0.52 mm long, 0.28 mm with high fixed valvae. When closed, the valva do not protrude beyond the tegumen. Tegumen indented distally. Valva elongated tapering distally and present long hairs on the apex. Saccus curved, distally covered with strong spines. Vinculum near the valva widest, evenly sclerotized, saccus distally very wide, slightly rounded. Phallus straight, shorter than genital length (0.31 mm), tapering distally. Presence of gnathos is not confirmed as they are invisible in the structure.

Larva. Larvae move actively on the hard objects like walls, gate, and concrete surfaces. The body of the larvae are light greyish colour and the head is highly sclerotized. The head capsule of the larvae is light yellowish with dark black patches on it. The length of a mature larvae is about 3–3.5 mm (Fig. 6).

Pupal case(male). the pupal case of males is dark golden-brown colour and measures about 3 mm in length (Fig. 7).

Larval cases. (Fig. 8 a, b) of this species are very small, sack like and conical in shape. Larval case is made up of small fragments of leaf and bark. Adult cases are almost cylindrical. The surface of the cases has a prickly appearance due to the presence of many minute spikes which are visible on close observation. Adult male cases measure 8.5–9.5 mm (2.1 mm width at centre). Cases of an adult female is slightly longer and wider than males (Fig. 8b); it measures about 11–12.5 mm (2.8 mm width at centre). Composition and structure of cases are similar in both sexes except size. The larval cases seemed to be attached directly to the leaf during pupation. At the same time on detaching the cases from the leaves, there were silken threads present. The thread becomes prominent during detachment or later in the course of weathering (Fig. 8c).

Female. (Fig. 9a,b): it is yellow, maggot shaped, with no wings and appendages. length 3.8mm. The head is clearly regressed, without any appendages. Sclerotization was observed on the head and thorax region and with dark brown in colour. Abdominal region is poorly sclerotized and packed with eggs.

DNA sequencing (COX1): The examined mitochondrial COX1 (Cytochrome oxidase I) gene of *A. alstoni* is 653 bp long. The sequence has been uploaded to NCBI GenBank and Accession number is ON584252. The nucleotide composition percentage of the species is 37.5(T), 17.3(C), 30(A), and 15.2(G).



FIGURE 5: Genitalia (male) dorsal view, mounted in Canada Balsam.

Distribution and Range. Larval cases were collected from three districts (Wyanadu, Idukki and Ernakulam) of Kerala. The places and locations are plotted in Figure 10. The altitude of the sites from where *A. alstoni* were collected ranges from 15 mASL to 1660 mASL. All sightings except Athani in Ernakulam (15 mASL) were above 700 mASL. The site at Athani was urban and predominantly a residential area with small homestead gardens around individual houses. All other sites were rural, in monoculture plantations near forest areas. The distance between the northern most observations to southernmost observation was 260km and east-west distance was 99 km. The diagonal area covered when joining all plots of observation was 12150 km² and its perimeter was 570.7 km. The diagonal area covered all types of land use and vegetation though all sites except Athani were situated near protected forest areas and near a wetland. Mean temperature range of the area was between 15°C and 35°C and rainfall was 350–450 cm.

Substrates and host plants. Larval cases and pupal cases were observed from Idukki and Ernakulam. Only pupal cases were observed from Wayanad. The larval cases were found moving actively on the hard surfaces such as walls, concrete slabs, building surfaces and also from live plants. The pupal cases were attached to different plant species. Significant damage to plants was not observed by this species. Maximum sightings of larval cases were from the surfaces of hard objects like walls, gates, etc in their larval stages. The pupae were attached mostly to the underside of leaves, twigs and bark. Nine species belong to eight families of plants are recorded as host plant of this species (Table 1).

Life Cycle. The larval cases showed activity for a few days after collection and then become immobile. On examination the larvae were found to be dead. *A. alstoni* could not be successfully reared in the laboratory as the caterpillars died in the bag. Therefore, complete life cycle and many other characteristics of the species need further evaluation. Pupal cases from locations with cooler temperatures and high altitudes (Idukki and Wayanad) showed no

emergence. Only cases collected from relatively higher temperature and lower altitude (Athani) showed emergence. Adults were obtained in the laboratory when they emerged from the pupal bags collected from the field. Therefore, the duration of various life cycle stages are indeterminate at present.



FIGURE 6: Larval case and dorsal view of larva of *Acanthopsyche alstoni*.

Discussion. *Acanthopsyche* Heylaerts, 1881 is one of the most widespread Psychidae genera (Dierl, 1972). All previously known species have wingspans over 10 mm. The smallest known oriental species of the genus, *Acanthopsyche minima* Hampson, 1900 is significantly larger with a wingspan of 12 mm. It was described from Sri Lanka (“Ceylon, Puttalam”): “Uniform black-brown, wings rather sparsely clothed with black hairs, rather more thickly on basal half of inner area of forewing. Larval case covered with small land-shells, bits of the pupae of a large moth”. The genus *Striglocyrbasia* Sugimoto & Saigusa, 2001 includes similarly small species with a wingspan of less than 10 mm. This differs generically by a reduced number of veins (7–8 from dc fore wing, 3–4 from dc hind wing).

At the beginning of the investigations the specimen characters were compared to various species of psychids (Sobczyk, 2011) and based on the observations it was placed in genus *Acanthopsyche*.

The characteristics of the specimen differed from other known species from the region. But the larval cases shape and size, attachment to the underside of the leaf and damage pattern in leaf (observed very rarely) matched with Watt & Mann (1903) original description: “*Acanthopsyche alstoni* (?) n. sp. Found in Duars. 371. This the smallest species of all, found doing damage at Sylee, Duars, in November 1900. The larval cases are less than ¼ inch long, suspected by a thread. The insect acts on underside of the leaf and perforates it into a mass of minute perforations like shot. It has not been noticed elsewhere. We have not yet succeeded in obtaining the moth of this species.”

The identity of *A. alstoni* could only be determined because there is no agreement in the larval cases of other species. Neither in the plant protection literature (Watt & Mann 1903) nor in taxonomic works (Hampson 1900) is there information on other larval sacs of similar size and shape.



FIGURE 7: Lateral view of pupal case (male)

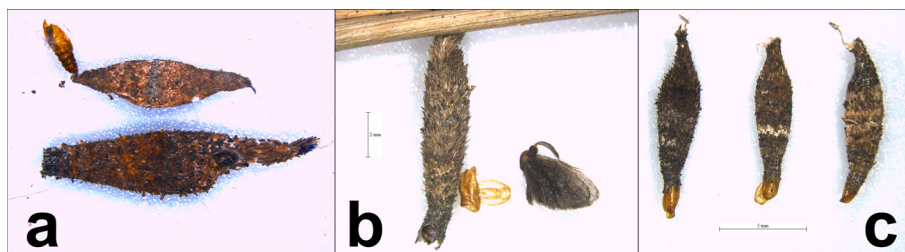


FIGURE 8a: Male and female cases; **b:** Male case, pupal case and adult; **c:** Male bags and pupal cases.

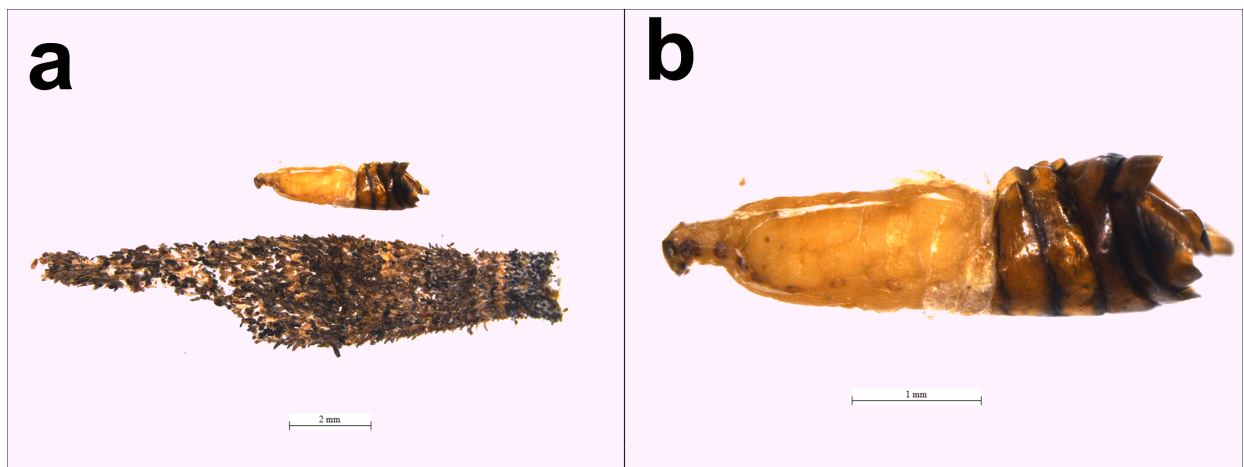


FIGURE 9a: Female case, pupal case and adult; **b:** Female adult.

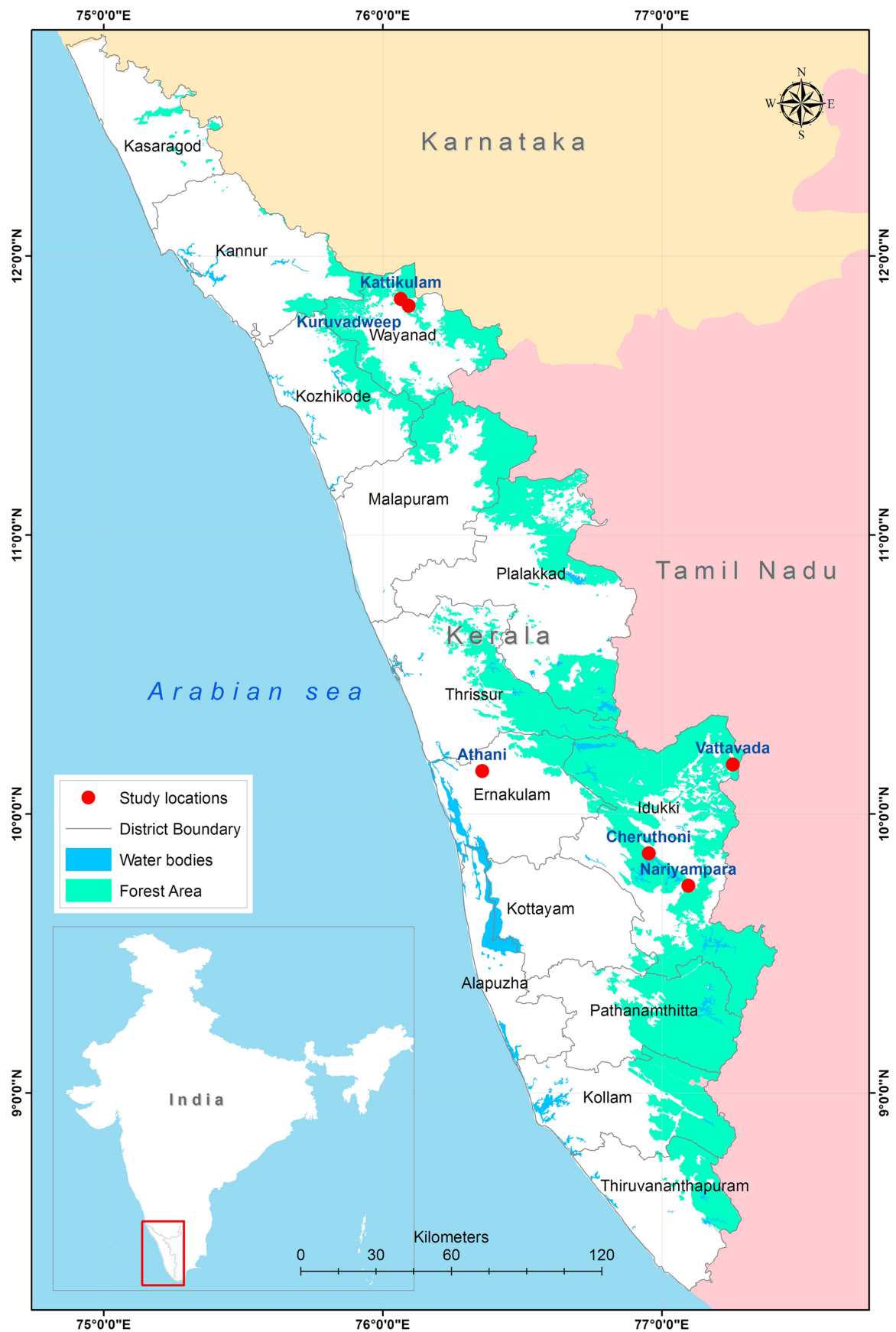


FIGURE 10: Distribution map of *Acanthopsyche alstoni*

TABLE 1. Host plants of *Acanthopsyche alstoni*.

No	Name of Plant	Family	Life stage of <i>A.alstoni</i> found on the plants
1	<i>Tradescantia spathacea</i> Swartz	Commelinaceae	Pupa
2	<i>Dracaena trifasciata</i> (Prain) Mabb.	Dracaenaceae	Pupa
3	<i>Dracaena reflexa</i> Lamarck.	Dracaenaceae	Pupa
4	<i>Grevillea robusta</i> A. Cunningham. ex R. Brown	Proteaceae	Pupa
5	<i>Araucaria heterophylla</i> (Salisbury.) Franco	Araucariaceae	Pupa
6	<i>Coffea arabica</i> Linnaeus	Rubiaceae	Pupa
7	<i>Madhuca neriifolia</i> (Moon) Herman Johannes Lam	Sapotaceae	Pupa
8	<i>Epipremnum aureum</i> (Linden & André)	Araceae	Pupa
9	<i>Ficus benamina</i> Linnaeus.	Moraceae	Larvae and pupa

Conclusion

As per ICZN regulations, a description based on the larval cases would no longer be possible and would be invalid. Though only the larval cases were described (Watt & Mann 1903) this was valid at the time of description. The name *A. alstoni* is therefore valid. Therefore, the specimens are placed in the species *A. alstoni*.

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Threat assessment of *Manatha albipes* Moore (Lepidoptera: Psychidae) from Kerala, India using GIS with comments on its taxonomy, biology, distribution and host plants

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Abstract

The detailed description of the distribution, morphology and relationships with host plants (19 species; 15 new records as host plants) of *Manatha albipes* from Kerala, India is presented here. Significant differences in the morphology from populations of *M. albipes* from other areas of India have been described. The larval stages of these moths are polyphagous and cause low to severe damage in host plants. The mitochondrial cytochrome oxidase 1 sequence of 692 bp length was sequenced and deposited in NCBI Genbank with the accession number MN717272. The sequence analysis confirms the identity of *M. albipes* as distinct from other closely related species of bagworms. *M. albipes* is not yet a major pest in Kerala but is emerging as a threat in the monocultures of neighbouring states. We demonstrate how many plant species in human altered habitations are carryover sources for *M. albipes*. Preliminary distribution map and threat analysis of the species in the state based on known land use data using GIS tools indicates large areas of agricultural land to be under threat.

Keywords Bagworm · Polyphagous · Cytochrome oxidase I · Genbank · Threat analysis · GIS

Introduction

Family Psychidae (Lepidoptera) has 1350 described species from 241 genera globally (van Nieukerken et al. 2011). They show high sexual dimorphism in adults in most of the species (Rhainds et al. 2009). The genus *Manatha* with the type species *M. albipes* was described by Moore (1877) from Sri Lanka (Ceylon). There are currently four known species of the genus *Manatha* (Table 1) of which *M. albipes* is economically critical as a pest of several crops. Many studies document *M. albipes* as a pest of multiple crops in India and Sri Lanka (Kurian et al. 1979; Nair and Daniel 1982; Dhileepan 1991; Josephraj Kumar et al. 2012; Kalidas and Saravanan 2018; Kalleshwaraswamy et al. 2018; Poorani et al. 2021).

To control a particular pest species, information about their biology and ecology is essential. The polyphagous nature of bagworms amplifies the chances of severe infestations and human altered areas around homesteads and agricultural land with a variety of plants can serve as reservoirs or carryover sources (Goodell 2009) for such pest populations. Documenting such areas may reveal the likelihood of future outbreaks. There was little information till Poorani et al. (2021) provided a comprehensive account of the species from Tamil Nadu and Karnataka.

In this context we present the first report of *Manatha albipes* from Kerala with a detailed description of the distribution, taxonomy and host plants which adds to the previous studies, based on data collected from May 2017 to August 2021. We also predict the areas which could be affected by the species.

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Materials and methods

Study area, collection, and identification

The specimens were collected from non-forested areas from eight districts (selected randomly by multistage sampling)

Table 1 Checklist of *Manatha* Moore (1877), Oiketicinae, Acanthopsychini

Species	Country
• <i>Manatha albipes</i> Moore (1877)	• Sri Lanka, India
• <i>Manatha assamica</i> (Watt 1898) = <i>Manatha scotopepla</i> Hampson, 1910 syn.nov	• India (Assam)
• <i>Manatha conglacia</i> (Hättenschwiler et al. 2013)	• Papua New Guinea
• <i>Manatha taiwana</i> (Sonan, 1935)	• China (Taiwan), Japan

of Kerala, India. Bags of the moth were picked from the host plants and reared inside rearing bottles. Details of host plants and bag attachment were recorded during collection and consolidated. Adult moths were used for morphological and molecular studies. Emerged male moths were sacrificed; spread, and pinned using standard protocols and morphometric measurements (body length, wings span, antennal length, and head width), wing venation, legs, antennae, genitalia and adult larval chaetotaxy were documented. Parasitoids collected from the bags during rearing were identified up to genus or family level and listed. Observations of micro characters were taken by using the binocular stereomicroscope (Leica S8APO). The characteristics of the larval bag and pupal case were also observed.

Molecular sequencing and Phylogenetic analysis

Molecular sequencing of cytochrome oxidase subunit 1 gene was done. DNA was extracted from the tissues of thoracic legs of male moth specimen using NucleoSpin® Tissue Kit (Macherey–Nagel). PCR amplification reactions were carried out. The sequencing reaction was done in a PCR thermal cycler (GeneAmp PCR System 9700, Applied Biosystems) using the BigDye Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems, USA). The sequence quality was checked using Sequence Scanner Software v1 (Applied Biosystems). Sequence alignment and required editing of the obtained sequences were carried out using Geneious Pro v5.1 (Drummond et al. 2010). The sequences were submitted to GenBank and accession numbers obtained. Clustal W software was used for the alignment and trimming of the final sequence. The nucleotide sequence was searched for similarity checking using nucleotide BLAST in NCBI. Phylogenetic tree construction was done in the software MEGA7 using the neighbor-joining method and the used 11 sequences were downloaded from the Genbank including two sequences by the authors (MN717271 *Eumeta crameri* and MN717272 *M. albipes*). Evolutionary analyses were conducted in MEGA7 (Kumar et al. 2016). The evolutionary history was inferred using the Neighbor-Joining method (Saitou and Nei 1987). The evolutionary distances were computed using the p-distance method (Nei and Kumar 2000) and are in the units of the number of base differences per site. There was a total of 665 positions in the final dataset.

Distribution map and threat analysis

A distribution map of *M. albipes* was created in QGIS by plotting the geo-coordinates of the species occurrences in the study area. Banana (*Musa* sp. Zingiberales; Musaceae) and arecanut (*Areca catechu*. Arecales; Arecaceae) plantations in neighbouring states have emerged as major points of *M. albipes* infestation (Poorani et al. 2021). Therefore, digital maps of areas in the state reported with similar land use and mixed plantations (Source: CESS Land use Maps) were used to demarcate agricultural land which could possibly be affected by *M. albipes*.

Results and discussion

Morphology

The adult male moths (Fig. 1) were medium-sized, narrow-bodied insects with uniform brownish wings. Wingspan 18–20 mm. forewing length 8.5 mm, forewing index 0.55 (forewing index was calculated by a maximum width of the forewing divided by its maximum length), antennae length 2.8 mm. Head covered densely with hair-like brown scales. Eyes are small, brown. Labial palpi fused. Tentorial pits and tentorium are pronounced. Adults show sexual dimorphism. Antennae (Fig. 2) have 20 segments, brown, covered dorsally with small, thin brownish scales. Segments bipectinated, ventrally with long cilia. On the sixth and seventh antennal segment reaching maximum length (nine-length of the antennal segment), to apex uniformly decreasing, scapus thickened, pedicellus disc-shaped. Mouthparts are

**Fig. 1** Adult moth



Fig. 2 Antenna of adult male moth



Fig. 3 Legs of adult male moth

reduced. Legs are elongated, brown (Fig. 3) and femur and tibia covered with brown scales. Tibia in the forelegs with long epiphysis. Tarsal segments are pure white. Thorax is brown scaled. Wings brown, without a discernable pattern.

Wing venation studies shows (Fig. 4) ten whitish veins from DC, $r3 + r4 + r5$ stalked and from outer corner DC, $m2 + m3$ short-stalked at the half. DC with a median stem. From $A1 + A2$ no branch to posterior margin. Hindwings with six veins from DC, $m2$, and $m3$ separate. DC in this

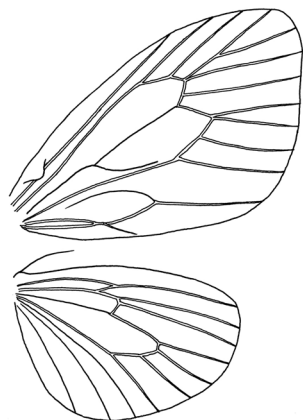


Fig. 4 Drawing of wing venation



Fig. 5 **a** Genitalia (male) dorsal view **b** Genitalia (male) ventral view

part extended to the outer margin. Median stem undivided in DC. Sc and rr merged at basis.

Genitalia (Fig. 5a, b) stretched, 1.5 mm long, with high fixed valvae. Tegumen is distally narrower, with two lobes. Valva anterior edge with short bristles distally rounded. The median base of the valva is connected by slender sclerotized bands. Anellus is short distally rounded, with a field of bristles. Sacculus straight, curved, distally with six curved thorns. Saccus evenly narrowed, distally rounded. Phallus 1 mm, strong, only slightly curved, distally significantly bulged.

Bag (Fig. 6a) of this species is whitish cream colour, cone-shaped, covered with pieces of thin bark or bits of leaves, the moulted head capsules of larval instar are

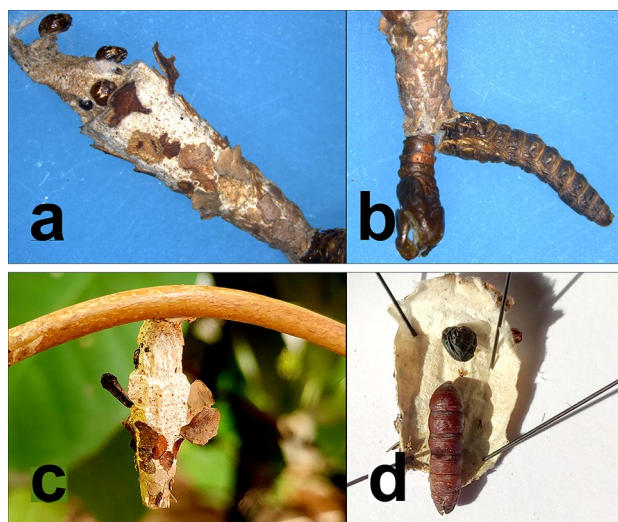


Fig. 6 **a** The male larval bag of *M. albipes* with moulted head capsules of larval instar **b** Distal end of bag with attached male pupal case and adult larval skin of *M. albipes* **c** The female larval bag of *M. albipes* **d** Inside view of female bag

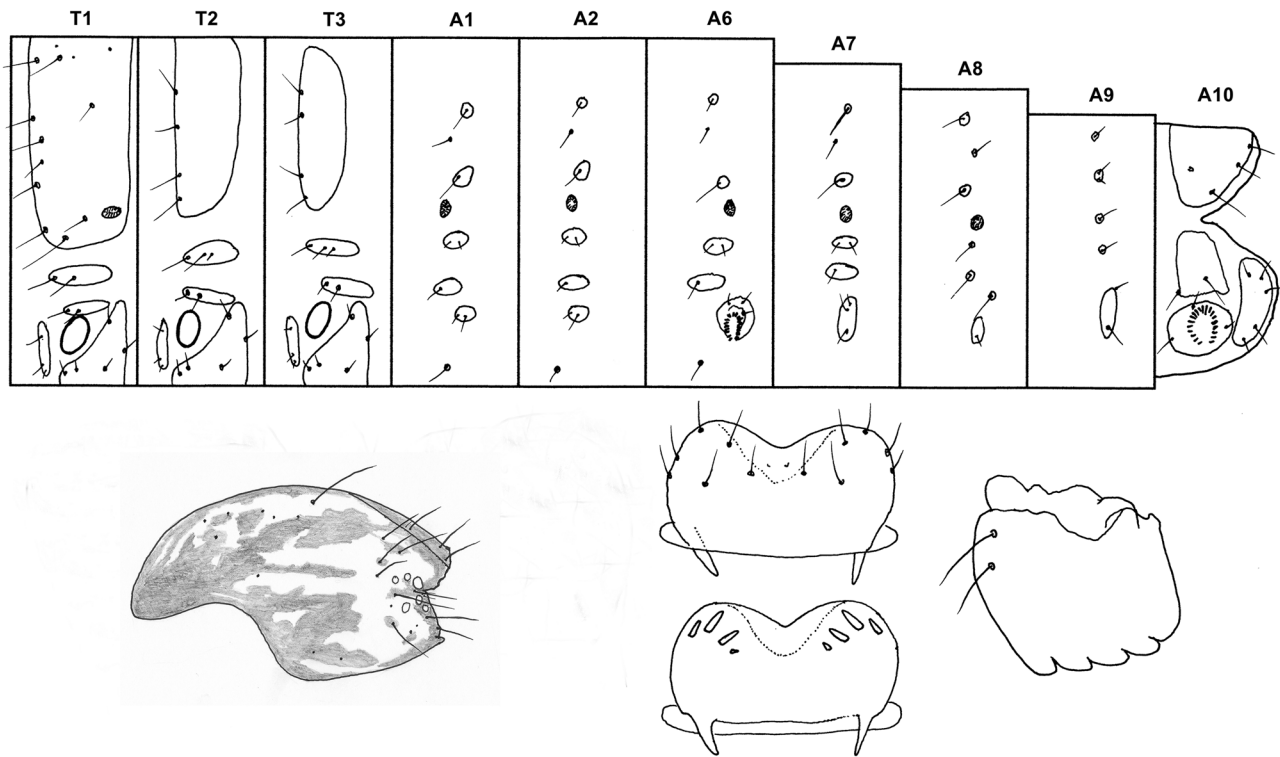


Fig. 7 Drawing of the larval chaetotaxy

attached around the bag. From the lower end of the bag, protrudes an empty pupa case from which the male insect has escaped (Fig. 6b). A mature male larval bag measure about 19.5 mm (including the anterior web-like region) and have anterior circumference 10.4 mm and posterior circumference 9.4 mm and has the outer diameter at anterior end

6.04 mm and posterior end 3.3 mm respectively. Larvae are dark black coloured actively moving and feeding on leaves. Female bags (Fig. 6c) are almost cylindrical. Compared to male bags they are longer and wider in size. A mature female bag length is 25 mm, anterior and posterior perimeters are 20 mm and 16 mm respectively. Pupal exuvia of female is

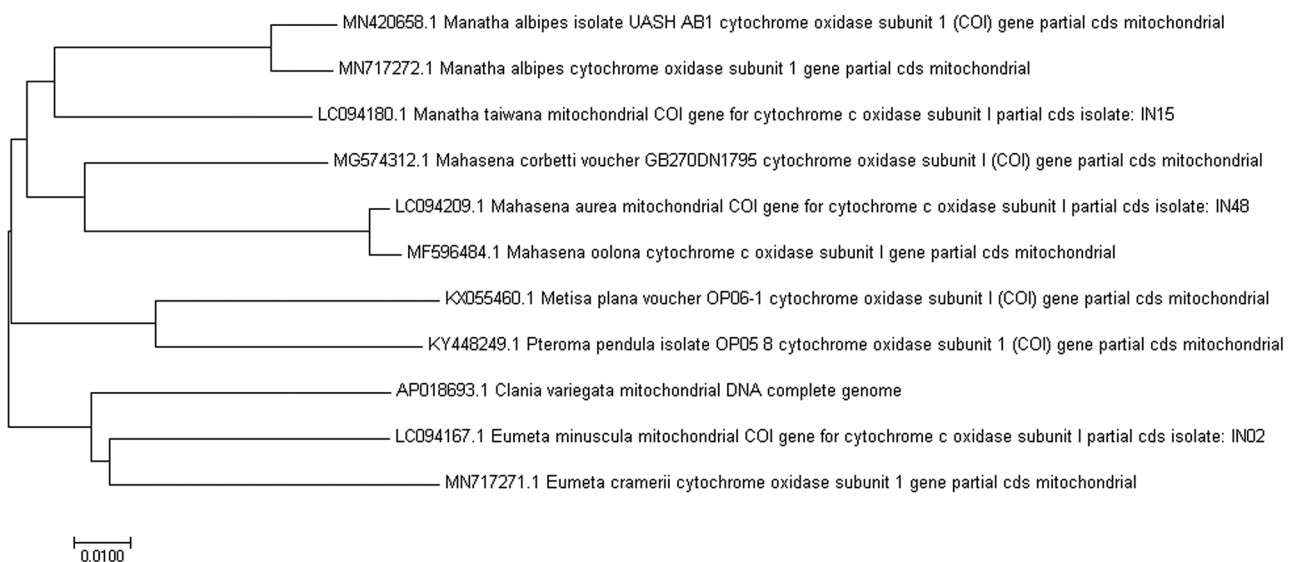


Fig. 8 Phylogenetic positions of *M. albipes* among other Psychidae reported from the region (Neighbour-joining method)

Table 2 List of host plants of *M. albipes*

Plant species	Type	Plant Order	Plant family	Relative incidence of <i>M. albipes</i> on host plants based on % of trees infected
<i>Terminalia catappa</i> *	TREE	Myrtales	Combretaceae	22.03
<i>Phyllanthus emblica</i>	TREE	Malpighiales	Euphorbiaceae	13.56
<i>Pongamia pinnata</i>	TREE	Fabales	Fabaceae	10.17
<i>Heliconia rostrata</i>	HERB	Zingiberales	Heliconiaceae	8.47
<i>Cocos nucifera</i> *	TREE	Arecales	Arecaceae	6.78
<i>Billbergia pyramidalis</i>	HERB	Poales	Bromeliaceae	5.08
<i>Syzygium samarangense</i>	TREE	Myrtales	Myrtaceae	5.08
<i>Dyopsis lutescens</i> *	SHRUB	Arecales	Arecaceae	3.39
<i>Cassia fistula</i>	TREE	Fabales	Fabaceae	3.39
<i>Lagerstroemia speciosa</i>	TREE	Myrtales	Lythraceae	3.39
<i>Musa x paradisiaca</i> *	HERB	Zingiberales	Musaceae	3.39
<i>Jasminum sambac</i>	SHRUB/VINE	Lamiales	Oleaceae	3.39
<i>Casuarina equisetifolia</i>	TREE	Fagales	Casuarinaceae	1.69
<i>Calliandra haematocephala</i>	SHRUB	Fabales	Fabaceae	1.69
<i>Tamarindus indica</i>	TREE	Fabales	Fabaceae	1.69
<i>Magnolia champaca</i>	TREE	Magnoliales	Magnoliaceae	1.69
<i>Hibiscus rosa-sinensis</i>	SHRUB	Malvales	Malvaceae	1.69
<i>Psidium guajava</i>	TREE	Myrtales	Myrtaceae	1.69
<i>Ixora coccinea</i>	SHRUB	Gentianales	Rubiaceae	1.69

* These species have been reported as host plant for *M. albipes* in previous studies also. All other plants species are new records as host plants

15 mm in length and found inside the female bag (Fig. 6d). Pupal case (male) has a length of 7.9 mm, a circumference of 9.4 mm, and a diameter 3 mm.

The above descriptions add to the report of Poorani et al. (2021). The major difference we noted from the description provided by Poorani et al. (2021) was the wing span greater by almost 5 mm; the predominantly black colour of the larvae and pure white tarsal segments. Poorani et al. (2021) also describe the adult female. Their study also notes marked differences among populations bred on different host plants exclusively. This phenomenon would explain the slight difference between the morphology of populations collected from Kerala, Tamil Nadu and Karnataka.

Larval chaetotaxy (Fig. 7) The adult male larva was examined, the skin of which remains outside the larval case during pupation and is spun with the head end. The maximum length measured was 11 mm and the maximum head width was 1.5 mm. The Head is dark brown sclerotized. Thoracic plates, including the sterna, are partly more heavily sclerotized, light brown with darker, less pronounced markings. Integument cream with partially light brown pinacula.

Head Epicranial notch reduced, two halves cranium only slightly separated. P1 arising anterior, longer than AF1. AF2 as long as AF1. Six stemmata are present. Labrum with six



Fig. 9 Larval bags of *Manatha albipes* on host plants



Fig. 10 Damaged leaves of *Syzygium samarangense*

pairs of dorsal setae, all well developed and approximately the same length; venter of the labrum with four pairs of epipharyngeal setae. Mandible relatively broad, with four distally rounded cusps.

Thorax Pronotum not divided median. This area breaks open linearly during pupation. Distance XD1-XD1 equal to distance D1-D1, distance D2-D2 smaller than XD2-XD2.

L1, L2, and L3 laterally on the pronotum, not on a separate pinacula. L1 and SV1 on a separate pinacula. Dorsal pinacula of mesothorax also fused, setae D1, D2, SD2, and SD1 arranged linearly. Metathorax with median separated dorsal pinacula.

Abdomen D1 and D2 on separate, small rounded pinacles on A1-8, together with SD1 on a narrow transverse pinacula on A9. SV bisetose on A1-8, unitose on A8 and A9. L-series trisetose on A1-7, where L1 and L2 arise together on a pinacula separated from L3. Anal plate with D2 absent. Prolegs 3–6 with 17–23 crochets in a uniordinal, lateral penellipse. Anal crochets 17–19. Larval chaetotaxy has not been discussed in detail by Poorani et al. (2021) and older descriptions.

DNA barcoding and phylogeny analysis

The PCR amplified product was 692 bp in length. The sequence was deposited in the NCBI Genbank with accession number MN717272. The BLAST results showed different range similarities with different species of Family Psychidae. The optimal tree with the sum of branch length = 0.53092105 is shown (Fig. 8). The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. The nucleotide sequence of *M. albipes* showed high similarity with the available *Manatha* species in Genbank ie; *M. albipes* of Tamilnadu, India with (GenBank accession MN420658, 97.74%) submitted by Poorani et al. (2021) and *M. taiwana* of Japan (GenBank accession LC094180, 90.38%) by Sugimoto and Saigusa (2001).

Host plants

Nineteen different plant species belong to 14 families were recorded as host plants of *M. albipes* (Table 2). Fifteen of

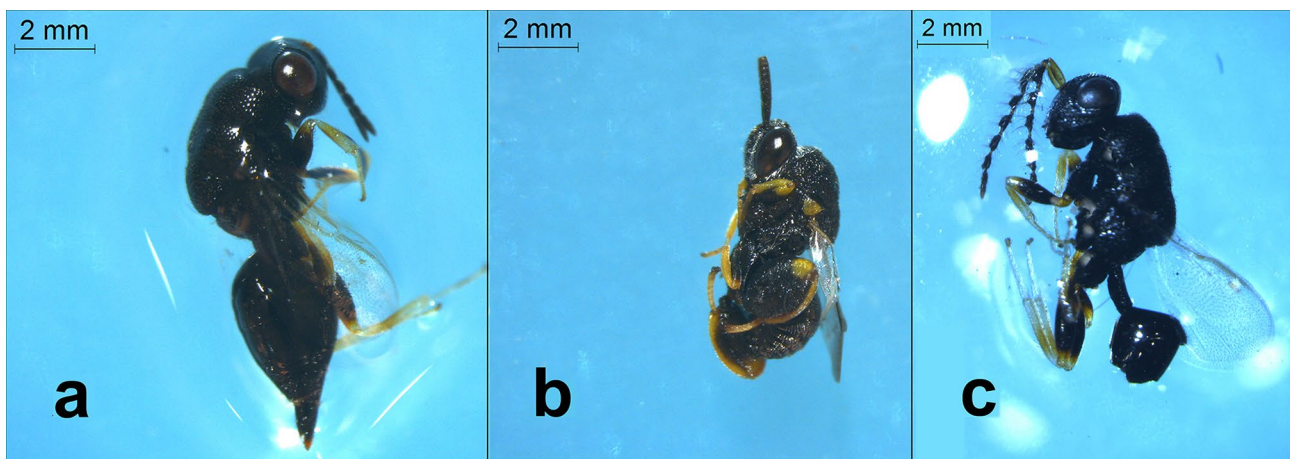


Fig. 11 a, b, c Parasitoids: *Brachymeria* sp, *Eurytoma* sp, unknown species

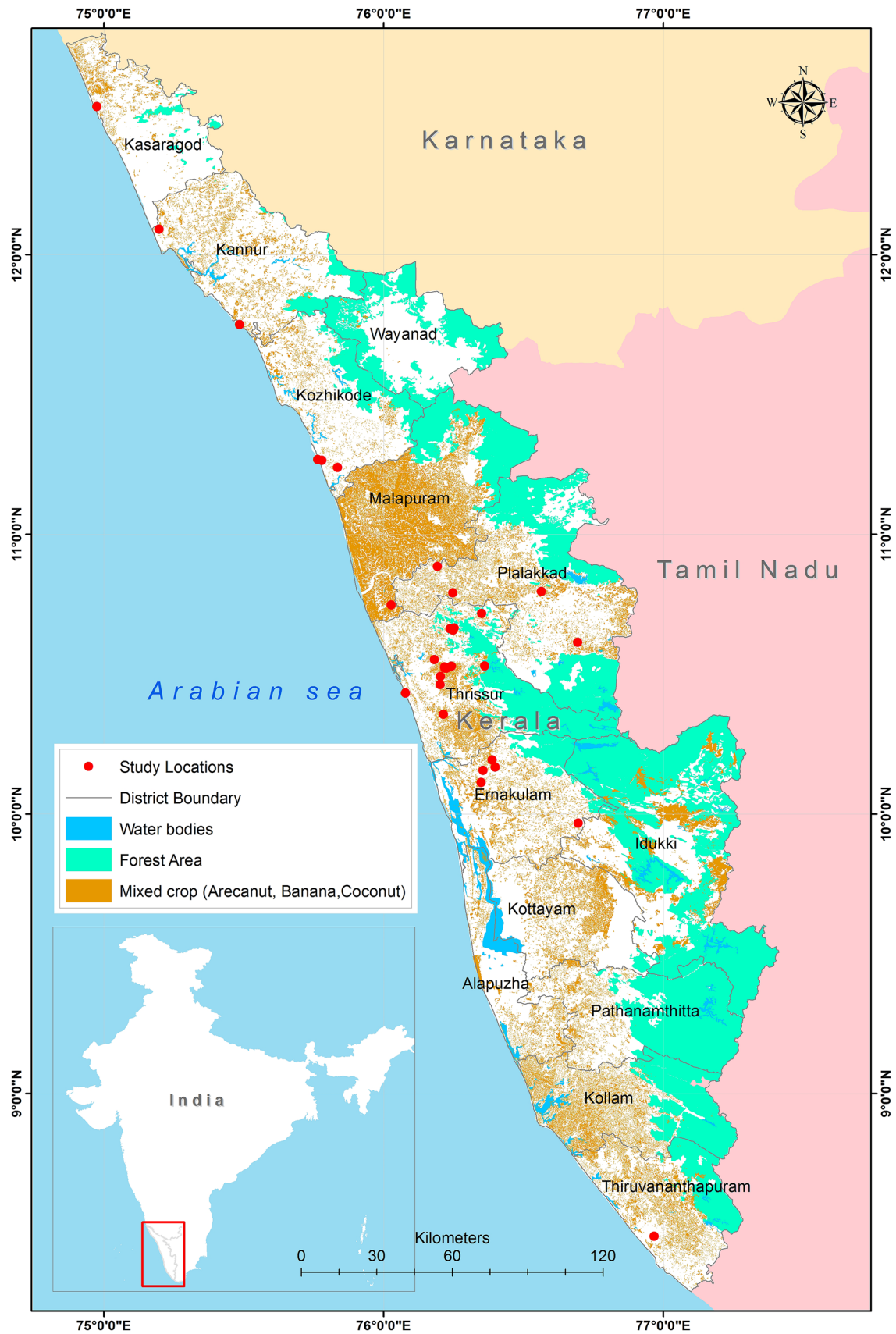


Fig. 12 Preliminary distribution and Threat analysis map of *M. albipes*

these species are new records as host plants of *M. albipes*. *Terminalia catappa*, *Phyllanthus emblica*, *Pongamia pinnata* were the most preferred host plants by *M. albipes*. Family Combretaceae and Fabaceae were the most affected plant families. *M. albipes* has recently emerged as a major pest of banana and arecanut in Tamilnadu and Karnataka (Poorani et al. 2021). Our sampling zones which were randomly selected were not concentrated on agricultural areas or specific plantations but in light of the findings of Poorani et al. (2021) we informally questioned some farmers with banana and arecanut in their homestead farms and they were able to identify the bag of *M. albipes* as seen on their plants even though they did not know what it was.

Bag attachment was seen in the internode, lamina, and bark region of the host plant. Most of them were trees and the bagworm cases aggregated on the middle or bottom halves of the trees especially in large groups on the bark region during their last instar or pupal stage (Fig. 9). The larve from earlier instars feeds the leaf lamina and makes holes on leaves and intense damage in the plants was observed in many cases (Fig. 10).

Extensive studies about the host plants of *M. albipes* were lacking in India, except the reports of infestations on some economically important crops like oil palm and coconut (Dhileepan 1991; Josephraj Kumar et al. 2012), banana and arecanut (Poorani et al. 2021). This study documents the widespread presence of the *M. albipes* from many host plants from all over the state of Kerala. These plants in and around agricultural lands and homesteads can serve as carryover sources and reservoirs of pest population (Goodell 2009) indicating the possibility that it could also emerge as a major threat to agriculture in Kerala.

Parasitoids

Seven parasitoid species from five different Hymenoptera families were recorded from bags collected from *Pongamia pinnata* (Fabales; Fabaceae) and *Tamarindus indica* (Fabales; Fabaceae). Parasitoids were *Brachymeria* sp (Chalcididae) (Fig. 11a), *Eurytoma* sp (Eurytomidae) (Fig. 11b), *Pediobius* sp (Eulophidae) and two unknown species from families Eurytomidae (Fig. 11c) and Eupelmidae were identified from the plant *Pongamia pinnata*. *Elasmus* sp (Eulophidae), *Paraphylax* sp (Ichneumonidae) are recorded from *Tamarindus indicus*.

Elasmus ceylonicus Ferriere and *E. hutsoni* Ferriere (Hymenoptera: Eulophidae) from Sri Lanka (Noyes 2019) *Brachymeria* sp. (Hymenoptera: Chalcididae), unidentified tachinid (Diptera: Tachinidae) and pentatomid bug *Eocantethecona furcellata* from Tamilnadu, India (Poorani et al. 2021) were the available reports about the natural enemies of *Manatha albipes*.

Distribution map and threat analysis

Bags of *M. albipes* were collected from 34 sites in human-altered (non-forested) areas of eight districts in Kerala. The species was found in 100% of the randomly selected study sites. 100% frequency of occurrence from all sample sites indicates that *M. albipes* is more widespread in distribution than previously thought. The straight-line distance from the Northern most point of observation to Southern most point was 502 km. Maximum distance between East and West observations was 70 km. Polygon made by connecting the points of observation covered an area of 17,280 km² which is about one by third of the state's total land area. The entire region did not show any significant differences in temperature and rainfall (<http://www.ecostat.kerala.gov.in/index.php/agriculture>).

Mapping potential areas of threat in the state by including areas under mixed and monoculture plantations of banana, arecanut and coconut (with other crops also) indicated that 5884.64 km² under threat of infestation (Fig. 12). Of this 528.99 km² are under banana and 957.39 km² were under arecanut cultivation. (<http://www.ecostat.kerala.gov.in/index.php/agriculture>). This is not just a large area but it represents the livelihoods of many farmers in an economy badly hit by the pandemic. Farmers would benefit if extensive awareness programs would be held regarding the threat posed by *M. albipes*.

Conclusion

M. albipes has been misidentified earlier as *Psyche assamica* (Dierl 1972). It has been misidentified as *Kophene cuprea* Moore from many places in India (Poorani et al. 2021). That the state of Kerala has not recorded significant pestilence due to *M. albipes* as recently reported from the neighbouring state could be because earlier infestations in the state may have been wrongly attributed to other species. Lack of large monoculture plantations of the host plants in the state; lower average temperatures, higher mean rainfall and number of rainy days per years in Kerala when compared to the neighbouring state; different dynamics between *M. albipes* and its predators and parasitoids could be factors which have prevented this insect from emerging as a major pest in this region? Recent changes in the land use of Kerala have seen construction of new highways and planting of trees (which are reservoir hosts for *M. albipes*—*T. catappa*, *P. emblica*, *P. pinnata* and *C. fistula*) along the highways to control heat and carbon emissions. With so many unknown factors governing the life cycle of *M. albipes* and ever-changing alterations in the land use a potential population boom and spread of this hitherto unnoticed

bagworm species cannot be ruled out. We suggest extensive survey to determine the full extent of its distribution and threat status and spreading awareness among the farmers to prevent outbreaks of serious nature.

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Declarations

Ethics approval The research does not involve human participants or animals. The research involves an insect pest.

Consent to participate The research involves an insect pest.

Conflict of interest The authors declare that they have no conflict of interest.

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DISTRIBUTION MAPPING AND HOST PLANT PREFERENCES OF THE BAGWORM *EUMETA CRAMERI* WESTWOOD 1854 FROM KERALA, INDIA¹

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Bagworms (Lepidoptera: Psychidae) are sexually dimorphic polyphagous insects with a unique life cycle. *Eumeta crameri* is a common species of bagworm in Kerala, India. This paper documents the distribution mapping of *Eumeta crameri* in Kerala by QGIS method, and also includes an account of its host plant selection and utilization. Morphology and life cycle of the species is also discussed. We observed more than 100 individuals of *Eumeta crameri* from 19 localities in randomly selected human habitations of Kerala. The plant family most preferred by *Eumeta crameri* was found to be Fabaceae, and bag attachment was mainly seen on the middle portion of the preferred plant or tree.

Key words: Lepidoptera, Psychidae, distribution mapping

INTRODUCTION

Bagworms (Lepidoptera: Psychidae) are characterized by the bag-making habit of the larvae, and extreme sexual dimorphism in adults. Family Psychidae constitutes 1,350 species in 241 genera (van Nieukerken *et al.* 2011), reported worldwide except from Antarctica. Hampson (1892) listed 36 species from “British India”, including Sri Lanka and Myanmar, which is the oldest record of bagworms from India. A recent study indicates 106 species belonging to 34 genera in India (Sobczyk 2011). In most species, only the male emerges as a winged moth from the bag, while the females are apterous and persist as an egg sac inside the bag (Rhainds *et al.* 2009).

Bagworms were recorded as occasional pests from forested areas in Kerala but their polyphagous nature, as well as deficient documentation in human-altered habitats, suggests that they can become serious pests, in light of climate change and land use change (Mathew and Nair 1983, 1986; Nair and Mathew 1992; Varma *et al.* 1989). Many species are defoliators of cultivated crops and cause moderate to severe economic damage (Basri 1993), so the documentation of these insects is significant.

Eumeta crameri Westwood is a common bagworm species in Kerala. It is found in different habitats and on various kinds of vegetation, including herbs, shrubs, and trees (Usha and Jose 2017). Up to four generations per year, with the male population much higher than the female (Ameen and Sultana 1977) were recorded from Bangladesh.

Thangavelu and Ravindranath (1985) did extensive work on the morphology and larval chaetotaxy of the species collected from Karnataka.

The present study documents the spatial distribution of *Eumeta crameri* Westwood by QGIS mapping and detailed study of host plant selection and utilization. Description of morphological characters like wing venation and genitalia, and observations on the life cycle are also presented in this paper.

MATERIAL AND METHODS

Study area and collection: Collections were made from randomly selected sites in seven districts of Kerala, namely Thrissur, Palakkad, Wayanad, Malappuram, Ernakulam, Thiruvananthapuram, and Kannur. The bags of *Eumeta crameri* were handpicked from the host plants. Position coordinates, host plants, bag attachment, were recorded at the time of collection. Once a bag was noticed on a plant, observations were made around that plant in all directions wherever possible till no more bags were seen.

Distribution mapping: The position coordinates recorded were tabulated according to the presence of species in each site, and maps were created in QGIS technology, based on the occurrence of species. Concentric buffer zones of 2 km each were created to predict the range of dispersal from a mother bag.

Host plant selection and utilization: Data collected during field work was classified as follows: i. Bag position

was noted as top, middle, and lower, by roughly dividing the plant into three equal parts. ii. Bag attachment was classified as “on stem” and “on leaf”. On stem, the attachments were classified as on node or on internode regions. On leaves, bag attachment was noted “on leaflet” or “on midrib”. iii. The bags were also classified as small, medium, and large, based on the length of the sticks used in the bag, or the size of the bag.

Damage to the leaves near the bags, and all over the host plant, due to feeding by the larvae was calculated as follows: Damaged leaves were randomly selected for measurement. Based on the damage observed in the plant parts, i.e. mainly in the leaf area, we gave different scores. For no damage observed, score zero; less than $\frac{1}{4}$ of the leaf area damaged, score 1; $\frac{1}{4}$ to $\frac{1}{2}$ of the leaf area damaged, score 2; and $\frac{1}{2}$ to $\frac{3}{4}$ of the leaf area damaged, score 3; more than $\frac{3}{4}$ of the leaf area damaged, score 4. The utilization of host plants by the bag moths based on the bag size (instars), bag position, number of bags, plant type, and feeding, was visualized using Principal Component Analysis (PCA).

Morphological study: The larvae were transferred into rearing bottles and kept until the emergence of adults. A few emerged male moths were sacrificed, spread, and pinned using standard protocol. The wing venation and genitalia were microscopically studied by preparing slides.

Lifecycle and dispersal: The study was conducted in an artificially created experimental set up with conditions similar to those in the wild. The larvae used in this study emerged from female bags of *Eumeta crameri* collected from Palakkad. The transfer of the hatched larvae to the plant top was done artificially and the distribution of larvae was observed. The larvae were released on a potted *Phyllanthus emblica* tree (hitherto referred as mother plant), placed near the wall of a building. The plant was kept on a plinth of height 53 cm, which raised the height to a total of 153 cm from ground level. Observations on the number of larvae dispersed, direction of dispersion, and number of larvae remaining on the plant, were noted. The number of larvae in each instar was noted and a survivorship curve was plotted.

RESULTS AND DISCUSSION

Distribution maps

Bags of *Eumeta crameri* Westwood, which are renovated by each instar and consist of silk and extraneous material like leaves, twigs, and thorns (Agrawal and Pati 2003), were collected from 19 sites in human altered areas of 7 districts in Kerala (Fig. 1). Distribution of *Eumeta crameri* was plotted using QGIS technology, according to the geographical coordinates of each collection site (Table 1). The larvae were seen to disperse and establish new bags up to 2 km away

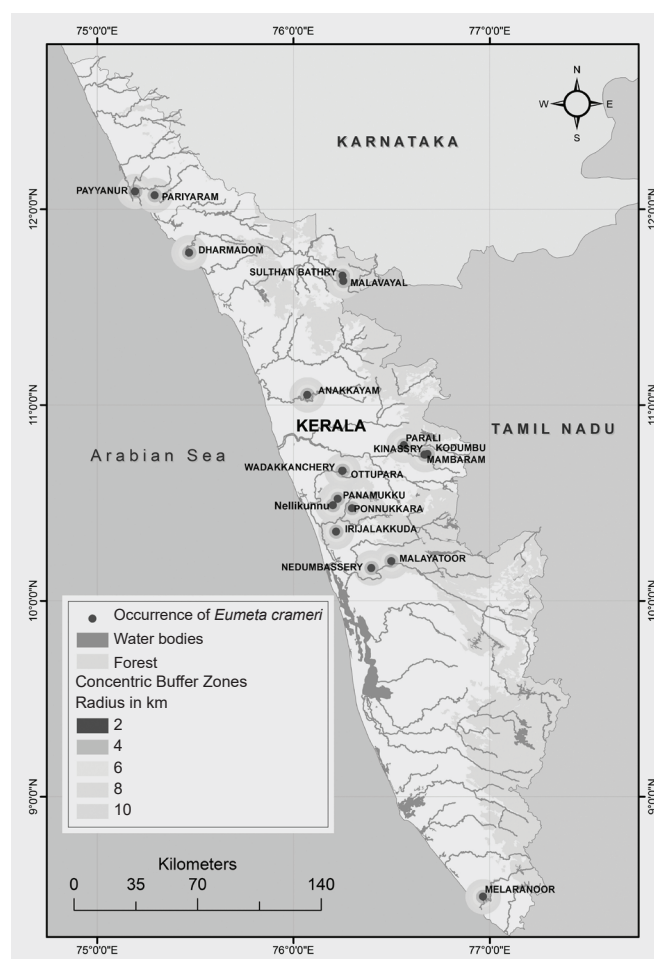


Fig. 1: Map of occurrence zones of *Eumeta crameri*

from the mother plant; the dispersal range of these insects was plotted upto five generations. Ameen and Sultana (1977) observed four generations in a year, while our own observations (71 days) indicate that 5.1 generations/year are theoretically possible. Based on the observed dispersal along a radius of up to two km per generation from the mother plant, dispersal up to 10 km radius from the mother plant was predicted per year (provided that all factors such as climatic conditions, availability of suitable host plants, and lack of predators were favourable) (Fig. 2).

Host plant selection and utilization: Bagworms in the study area show polyphagy, as 24 species of plants belonging to 14 known and 3 unknown families were seen to be infested by bagworms. Out of 24 species, 8 were trees, 6 were herbs and 10 were shrubs. *Phyllanthus emblica*, *Terminalia catappa*, *Psidium guajava*, *Tamarindus indica*, *Lawsonia inermis*, and *Hibiscus rosa-sinensis* were frequently found infested by *Eumeta crameri*, and Fabaceae was the most affected plant family (Fig. 3). The bags were mostly positioned in the middle of the host plant, irrespective of the species being a tree, herb,

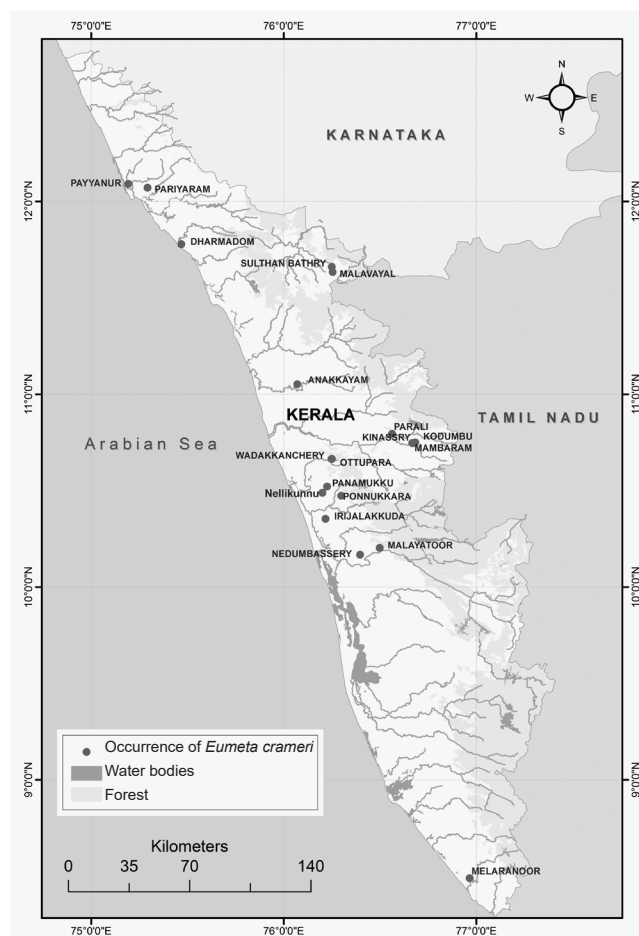


Fig. 2: Concentric zones showing hypothetical range of dispersal from the mother bag

or shrub (Fig. 4). The maximum number of bag attachments was seen at the internodes (Fig. 5).

Bags on the leaves were fewer in number than those attached to the stem. Though more bags were found in the middle third of the host plant in general, there was a significant increase in the bags attached to the upper third in trees, compared to shrubs and herbs. Less feeding was observed in trees than in shrubs and herbs.

Results of previous studies (Usha and Jose 2017) indicate that the mature larval instars migrate to trees after feeding on herbs and shrubs in the early instars. Relative size of the bags collected from the trees and reduced feeding (less damage observed) shows that mature larvae move to trees before pupation. This could indirectly help in better dispersal of the larvae, as air currents assist the ballooning technique used by larvae for dispersal.

While small and medium sized bags did not show any special preference for the top, middle, or lower parts of the host plant, and kept moving about, larger bags remained in the top region and were not observed to move much. As

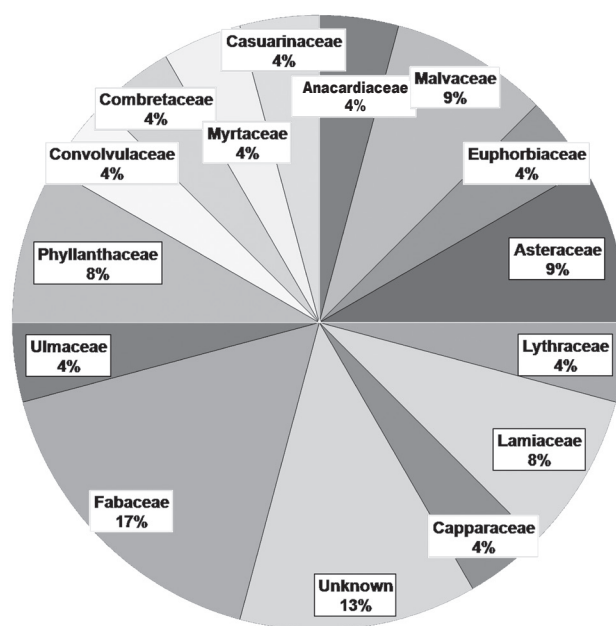


Fig. 3: Distribution of host plant families infested by *Eumeta crameri*

larger bags contain the final instars which feed less, as well as the pupal stage and egg sac-like adult females, they are less mobile, whereas the smaller bags move about actively and their larvae feed voraciously, dragging the bag from one host plant to another. The maximum feeding was seen on herbs and shrubs. The size of the host plant was negatively correlated to feeding damage, but not significantly so. More feeding damage was observed in the top third of the host plants, as there are tender and succulent twigs and leaves on the upper part of the stem which the bagworms prefer.

Principal Component Analysis: The PCA biplot (Fig. 6) based on the moth bag size (instars), bag positioning, and number of bags, plant type, and feeding indicate that *Mangifera indica* was unique among the host species, as the number of bags found on *Mangifera indica* was much higher other than plants and also because the majority of the bags were final instars. *Phyllanthus emblica*, *Trema orientalis*, *Tamarindus indica*, *Lawsonia inermis*, *Mangifera indica*, *Hyptis suaveolens*, and *Psidium guajava* form a cluster in which most of the trees were included. Other plants cluster together towards the centre of the biplot, indicating that more data is needed to delineate host plant preferences.

Plant species code: *Acacia auriculiformis* = AA, *Casuarina* sp. = C1, *Chromolaena odorata* = CO, *Cleome viscosa* = CV, *Crotalaria pallida* = CP, *Hyptis suaveolens* = HV, *Ipomoea marginata* = IM, *Lawsonia inermis* = LI,

Table 1: Occurrence data of *Eumeta crameri* Westwood

Sl no	District	Locality	Latitude	Longitude
1.	Ernakulam	Malayatoor	10° 12' 11.16"	76° 29' 56.4"
2.	Ernakulam	Nedumbassery	10° 10' 4.44"	76° 23' 52.08"
3.	Kannur	Pariyaram	12° 4' 16.68"	75° 17' 35.88"
4.	Kannur	Payyanur	12° 5' 27.708"	75° 11' 37.14"
5.	Kannur	Dharmadom	11° 46' 41.52"	75° 28' 8.4"
6.	Malappuram	Anakkayam	11° 3' 6.48"	76° 4' 17.04"
7.	Palakkad	Kinassery	10° 44' 49.344"	76° 40' 6.924"
8.	Palakkad	Mambaram	10° 44' 47.69"	76° 40' 14.376"
9.	Palakkad	Kodumbu	10° 45' 0"	76° 41' 2.4"
10.	Palakkad	Parali	10° 47' 41.21"	76° 33' 47.81"
11.	Thiruvananthapuram	Melaranoor	8° 29' 19.33"	76° 57' 59.8"
12.	Thrissur	Panamukku	10° 29' 18.204"	76° 12' 7.02"
13.	Thrissur	Nellikunnu	10° 31' 14.88"	76° 13' 33.96"
14.	Thrissur	Ponnukkara	10° 28' 24.0"	76° 17' 57"
15.	Thrissur	Irinjalakkuda	10° 21' 12.096"	76° 13' 4.73"
16.	Thrissur	Wadakkanchery	10° 39' 51.84"	76° 14' 57.48"
17.	Thrissur	Ottuppara	10° 39' 52.2"	76° 15' 5.4"
18.	Wayanad	Sulthanbathery	11° 39' 38.84"	76° 15' 2.27"
19.	Wayanad	Malavayal	11° 38' 0.456"	76° 15' 16.56"

Mangifera indica = MI, *Mikania micrantha* = MM, *Mimosa pudica* = MP, *Phyllanthus emblica* = PE, *Phyllanthus myrtifolium* = PM, *Phyllanthus reticulatus* = PR, *Psidium guajava* = PG, *Sida acuta* = SA, *Tamarindus indica* = TI, *Tectona grandis* = TG, *Terminalia catappa* = TC, *Trema orientalis* = TO, Unknown sp. 1 = U1, Unknown sp. 2 = U2, Unknown sp. 3 = U3, *Urena sinuata* = US.

MORPHOLOGY

The identification of species was done with the help of Hampson (1892), referring to experts, and also from the sequenced molecular data by BLAST. The Cytochrome oxidase subunit1 of *Eumeta crameri* was sequenced and uploaded in GenBank with the accession number MN717271.

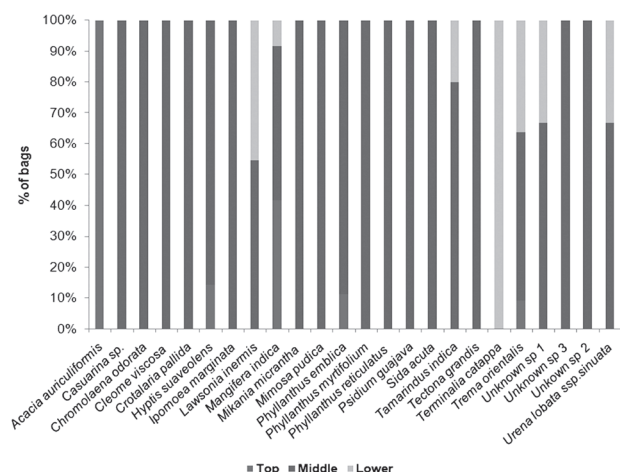


Fig. 4: Graphical representation of bag positioning on plants in each plant species

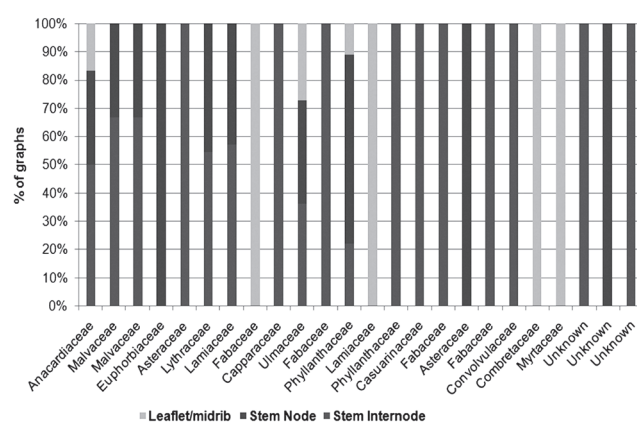


Fig. 5: Graphical representation of bag attachment on plants in each plant make it family

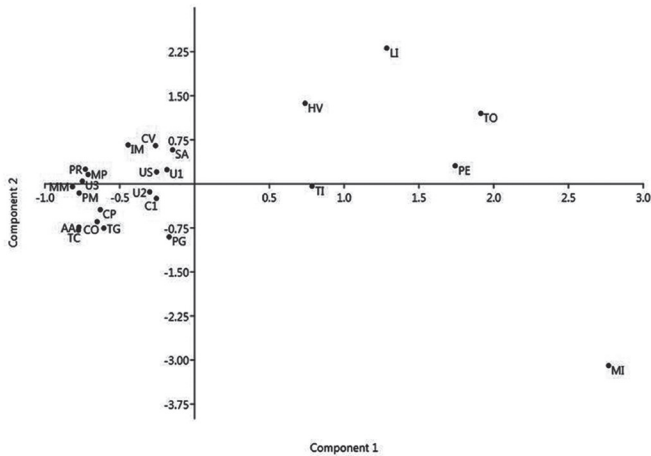


Fig. 6: PCA map showing three plant clusters based on utilization by bagworm moth larvae and bag attachment

The bag of this species (Fig. 7) is cylindrical, mainly made by attaching dry twigs from the host plants in a circular pattern, as described by Agrawal and Pati (1995, 2003). Before attaching the twigs, the larva makes a tough leathery silk bag

around its body, on to which cut twigs are attached using silk threads. The silk bag is whitish cream and open at the anterior and posterior ends. Most of the bags have one especially long stick. Mean measurements of mature larval bags were 38 mm length, 30 mm circumference, and 9 mm outer diameter. Our observations concurred with earlier studies in northern India (Agrawal and Pati 1995, 2003). Similar data was not available in the studies conducted in Bangladesh (Ameen and Sultana 1977) and Karnataka (Thangavelu and Ravindranath 1985). The larvae stay inside the bag throughout their lifetime, with only the head and thoracic legs protruding outside while feeding and moving about. Newly hatched larvae are pale buff, becoming dark brown or black as they grow.

Mean length of the newly hatched larvae was 1 mm. As described earlier by Agrawal and Pati (1995, 2003), the larvae reconstructed and increased the bag size by using longer sticks at each progressive instar. Thangavelu and Ravindranath (1985) have provided detailed descriptions of the larval stages of *Eumeta crameri* population from Karnataka.

Adult males (Fig. 8) are medium-sized (mean body length 11 mm), dark brown, with almost transparent wings; head,



Fig. 7: Larval bag



Fig. 8: Adult male

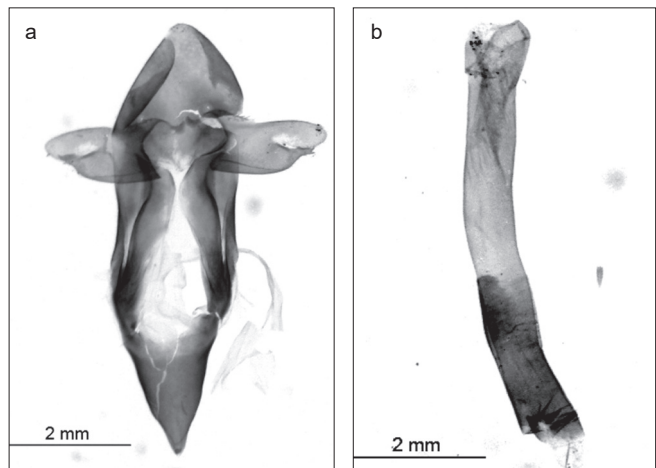


Fig. 9: a. Male genitalia, b. Aedeagus

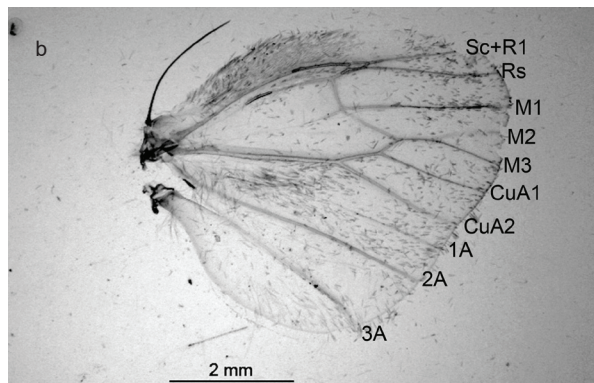
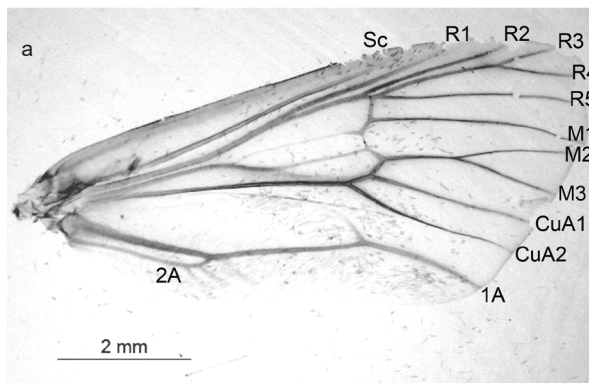


Fig. 10: a. Forewing. b. Hindwing

thorax, and abdomen are covered with light brown hairs. The upper parts of forewings and hind wings are covered with tiny brown scales. Head small, capsule-like with one pair of compound eyes, mean length 1.5 mm, antennae bipectinate. Legs pale brown with dark brown hairs covering the coxa to femur region. Fore and mid legs with thick brown hairs, mean length 8.5 mm and 6.6 mm respectively. Forelegs with elongated hair-like process parallel with the length of tibia, originating from tibia-tarsal segment or junction. Hind legs comparatively shorter mean length 4.5 mm.

Adult females are distinct from males, cylindrical (vermiform) in shape with the appearance of an egg sac. Body filled with pale yellow eggs inside a sac, and with partially sclerotized head. Appendages are lacking.

Wing venation: Wingspan 26 mm. (Fig. 10a, b) Wings almost triangular in shape, transparent in spite of the presence of scales; major veins clearly visible. All 12 veins in forewing and 8 veins in hind wing as reported by Hampson (1892) were seen in the specimens collected from the study area. Forewing with vein R3 and R4, M2 and M3 stalked, as described by Hampson (1892). Hind wing in some individuals showed an interconnected cell-like structure between the middle of veins 7 and 8. Veins M2 and M3 in hind wing were stalked.

Genitalia: (Fig. 9a) Male genitalia a long tube-like structure measuring 3 mm. External genitalia consist of the tip of aedeagus and valve, which protrude out of the last abdominal segment. Aedeagus (Fig. 9b) long tube-like, with cup-shaped anterior end measuring 2 mm.

Lifecycle and larval dispersal: Male and female bagworms do not possess any distinguishable external characteristics, so it is difficult to differentiate their bags in the early instars. In the final IXth instar, males are smaller and lack pigmentation (Thangavelu and Ravindranath 1985). The newly hatched (first instar) larvae were active and dispersed from the mother plant to the nearest plants by ballooning with the wind current. They build their bag by using silk and plant materials within 2 or 3 hrs after hatching. The wind was the primary medium of their dispersal. There was no feeding observed before ballooning. All the larvae were seen spinning silky threads for ballooning. The dispersal was carried mainly to the north-east direction following to the direction of wind (Usha and Jose 2018). The larvae form a single line while ballooning and move forward with the wind current. Dispersed larval bags were rediscovered after a few days from various plants around the mother plant, with the larvae actively feeding and building bags. Bags were not marked due to its minute size but the experiment was carried out in a wall compound and all plants were regularly checked before and after dispersal of bags, initial number of bags on

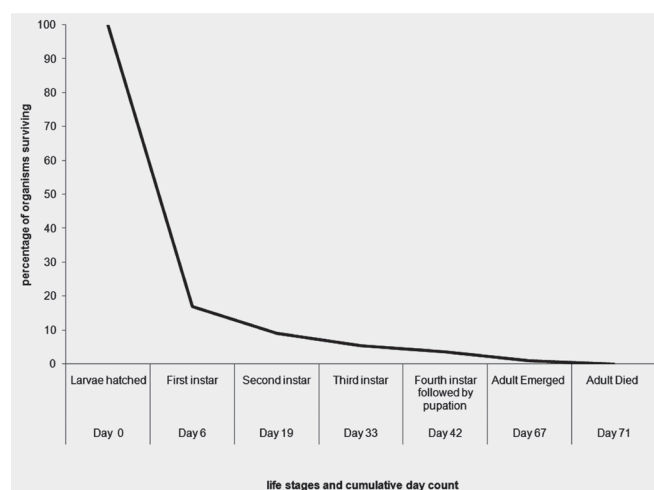


Fig. 11: *Eumeta crameri* Survivorship curve

the mother plant and final number of bags on other plants were compared and the latter was much less.

According to Usha and Jose (2018), out of 200 larvae hatched in natural conditions, only 34 relocated, to 12 individual plants of 5 species. The total lifecycle was of 71 days duration, larval and pupal duration was 42 and 25 days respectively. Adult lifespan is 3–4 days. A previous study (Agrawal and Pati 2003) stated that *Eumeta crameri* has three bag renovations, i.e. four instars per generation. But Thangavelu and Ravindranath (1985) delineated nine larval instars, based on the morphometric analysis of larvae. In this study, the life stages of *Eumeta crameri* were delineated based on bag renovations and a survivorship curve was plotted using the number of larvae at the time of each bag renovation.

Survivorship curve: The survivorship curve of *Eumeta crameri* was Type III or concave type. (Fig. 11). This species produced large numbers of offspring and the mortality of larvae increased in each progressive bag renovation. Only two adult moths emerged in a generation from a brood of more than 200. There are various reasons for a species to exhibit a particular survivorship curve; environmental factors could be the reason for decrease in survival. “An outside element that preferentially reduces the survival of young individuals is likely to yield a Type III curve” (Demetrius 1978).

CONCLUSION

The Bagworm Moth *Eumeta crameri* Westwood is one of the commonest bagworm species found in the study area. The distribution mapping and host plant preferences of this species enable an understanding of the ecology of

this common moth. Four different studies conducted in four different environments and time periods, with differing results, reveal that variations in the duration of its lifecycle could be influenced by environmental parameters. Further studies on the effect of specific climatic and other abiotic factors on the life cycle and dispersal of *Eumeta crameri* are essential, as climate change and other anthropogenic factors may transform this polyphagous low-profile feeder into a major agro-economic destructor.

ACKNOWLEDGEMENTS

We are indebted to UGC-NFSC for financial assistance. We thank our Principal and Head of the Department of Zoology, St Thomas College (Autonomous), Thrissur, for the facilities provided for our research work. We are grateful to Dr Anto P.V., Department of Botany, St Thomas College (Autonomous), Thrissur, for confirming the identification of host plants.

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**PRELIMINARY MAPPING OF SPATIO-CLIMATIC PREFERENCES
AND POLYPHAGY IN DIFFERENT SPECIES OF BAGWORMS
(INSECTA, PSYCHIDAE) FROM HUMAN HABITATIONS OF KERALA**

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Abstract

Bagworms (Lepidoptera: Psychidae) are bag building insects showing unique life cycle and sexual dimorphism. Polyphagous nature and deficient documentation from human-altered habitats present them as high potential pests in light of climate change and land use change. Random survey in the study area was done to collect bags of moths and details of host plants. Relevant environmental characters were also recorded. Six species of which three have been identified till generic level were recorded. Altitudinal range of *Eumeta* sps was 10-908 ASL and the mean altitude was 235.38. Altitudinal range of *Brachycyttarus* sps was 2-73 and mean altitude is 26.5. *Pteroma* sps had altitudinal range of 3-25 and mean altitude 17. Species 4, 5 and 6 are unidentified and have a altitude range of 25-33 ASL, 42 and 16-22 MSL respectively. Most of the species fell in the range of 30-50 cm for North eastern rainfall, 100 to 300 cm for South Western rainfall and 30 to 50cm for other rains combined. They all fell in the same temperature range of 18-35 Celsius. A total of 27 host plant species was recorded for six different species or types of bagworms. *Phyllanthus emblica* and *Terminalia catappa* were preferred by five of the six recorded species. Wide geographical distribution, tolerance to climatic fluctuations and established polyphagy indicates that bagworms have the potential to cause severe damage.

Keywords: Bagworm, Psychidae, *Eumeta*, *Brachycyttarus*, *Pteroma*

Introduction

Members of the Family Psychidae are commonly called bagworms, bagworm moths or bag moths because of their bag making behavior. Bagworms make bags around their body with different types of materials such as silk threads, plant twigs, leaves, thorns, etc and they complete their life cycle inside their bags (Agrawal and Pati, 2003). The bagworm family has 1350 described species from 241 genera globally (Nieukerken et al., 2011) except Antarctica. Hampson (1892) listed 36 species from British India including Sri Lanka and Myanmar and is

supposed to be the oldest record of bagworms from India. A recent study (Sobczyk, 2011) indicates the presence of 106 species belonging to 34 genera in India. In most species, only the male insect emerges as a winged moth from the bag while the females are apterous and persist as an egg sac inside the bag (Rhainds et al., 2009). The documentation of these insects are very significant because of being polyphagous, several species are defoliating pests of cultivated crops causing moderate to severe economic damage (Basri, 1993).

There are many records from Southeast Asia, of serious damage caused by bagworms in Palm plantations and other plants of economic importance (Shah et al., 2016).

Even though bagworms have not manifested themselves as a major pest in Kerala, there is always a chance that they may become one due to unwise agroforestry practices, habitat disturbances, and climate change. Paucity of data and systematic surveillance has led to a lacuna in recent scientific literature based on comprehensive studies of bagworms from Southern India. This study is a preliminary attempt for mapping the spatio-climatic preference and polyphagy in bagworms from different areas of Kerala.

Study area and Methodology

The data were obtained by surveying for bagworms from randomly selected areas of Kerala state, India during the last 18 months. Bags were handpicked, collected and reared inside the rearing bottles. Abiotic factors such as latitude and longitude, temperature, humidity, rain fall, wind speed etc and host plant details were noted at the time of collection. The geocoordinates were plotted on Survey of India (SOI) toposheets using QGIS (open source GIS software) to generate maps. To find out the rainfall range, temperature range and altitude, maps from resource atlas published by CESS were overlaid on the location map. The results were compared with those obtained from ground truthing. The obtained data was also statistically analyzed using appropriate statistical tests (dendrogram generated by Bray Curtis algorithm in PAST software).

Results and Discussion

Six different taxa were identified of which three have been identified till generic level. (Sp.1 *Eumeta*, Sp2 *Brachycyttarus*, Sp 3 *Pteroma*. Sps 4, Sp 5 and Sp 6 are unidentified at present.

Altitudinal Preference: Sp 1(*Eumeta*) had the range of altitude is 10-908 and the mean altitude are 235.38 and Sp 2(*Brachycyttarus*) had the range of 2-73 and mean value are 26.5. Sp 3(*Pteroma*) has the range of 3-25 and mean value is 17, Sp 4 ranges 25-33 and mean value is 30. Sp 5 has no range because it was collected only from one location and the altitude is 42. Sp 6 have the range of 16-22 and mean value is 19 (Fig 1).

Rainfall

- a) **Northeast (NE) Rainfall in cm (data from resource atlas maps issued by CESS):** In the case of Sp 1, the NE rainfall range is 30-50 cm and the average was 35.8 cm. For Sp 2 NE rainfall ranges was 30-50 and mean 39 cm. Sp 3 was mostly collected from NE rainfall zone of 40cm. Sp 4 had 40-50 and mean value was 46.6 cm. Sp5 and Sp6 were collected mostly from NE rainfall zone of 30 cm.
- b) **South West (SW) Rainfall in cm (data from resource atlas maps issued by CESS):** The average SW rainfall for Sp 1 distribution range was 225 cm and it ranges to 100-300 cm. For Sp 2 the range was 100-300 cm and mean value was 240 cm. Sp 3 fell in the SE rainfall zone of 250cm. Sp 4 had range of 100-250 and average of 150 cm,. Sp 5 and Sp 6 were observed from SW rainfall range of 300 and 250 cm respectively.
- c) **Other rains in cm (data from resource atlas maps issued by CESS):** The average rainfall of the sp 1 was 35.8 cm and ranges between 30-50. For Sp 2 mean was 39 cm and ranges between 30-50. Sp 3, 4 and 6 had the mean value of 44 cm and ranged 40-50. The mean value of sp 5 was 30 cm.

Temperature

All the six species fell in the same temperature zone ranging between a minimum of 18°C and a maximum of 37°C.

While all the six species of bagworms fell under the same temperature zone, it was observed that Sps 6, 2 and 3 were most similar in habitat selection based on the three types of rainfalls (SW, NE and other) trends followed by Sp1, Sps 4, 5 were most different. Sps 1 and 2 were also most cosmopolitan regarding altitude range (Fig. 1).

Host Plant and Polyphagy

A total of 27 host plant species was recorded for six different species of bagworms. From this, two species namely *Phyllanthus emblica* and *Terminalia*

catappa were commonly preferred by five species out of six of the recorded bagworm species. *Psidium guajava* plant was preferred by three species of bagworms and *Ipomoea purpurea* by two species.

Table 1: List of host plants

Sl. No.	Name of the Host plant	Sl. No.	Name of the Host plant
1	<i>Acacia sp.</i>	14	<i>Mikania miracantha kunth</i>
2	<i>Annona muricata</i>	15	<i>Pennisetum setaceum</i>
3	<i>Calliandra haematocephala</i>	16	<i>Phyllanthus emblica</i>
4	<i>Cardiospermum halicacabum</i>	17	<i>Phyllanthus reticulatus poir</i>
5	<i>Cleome viscosa</i>	18	<i>Piper nigrum</i>
6	<i>Epipremnum aureum</i>	19	<i>Pongamia pinnata</i>
7	<i>Heliconia sp.</i>	20	<i>Psidium guajava</i>
8	<i>Hibiscus rosasinensis</i>	21	<i>Sida acuta</i>
9	<i>Hyptis suaveolens</i>	22	<i>Syzygium gardeneri</i>
10	<i>Ipomoea purpurea</i>	23	<i>Tamarindus indicus</i>
11	<i>Lawsonia inermis</i>	24	<i>Terminalia catappa</i>
12	<i>Libidibia coriaria</i>	25	<i>Trema orientalis</i>
13	<i>Mangifera indica</i>	26	<i>Urena lobata</i>

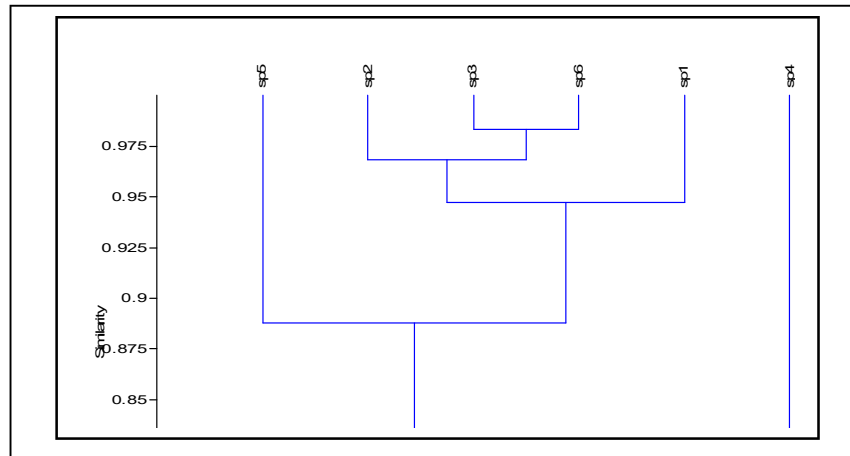


Figure 1: Dendrogram based on similarity in rainfall (NE, SW and other) ranges of bagworm species

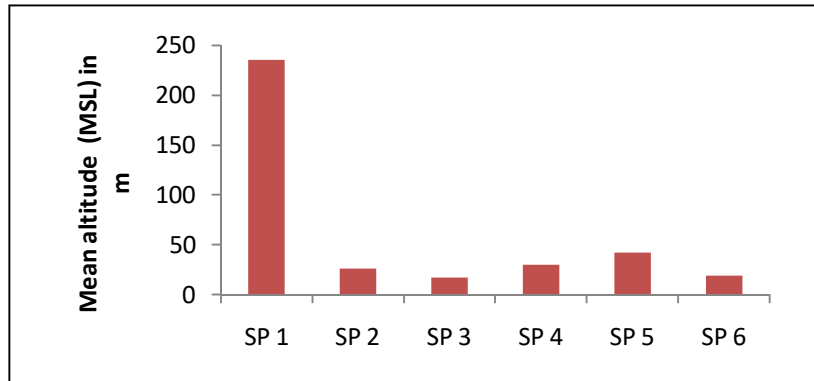


Figure 2: Bar diagram showing the altitudinal difference between species

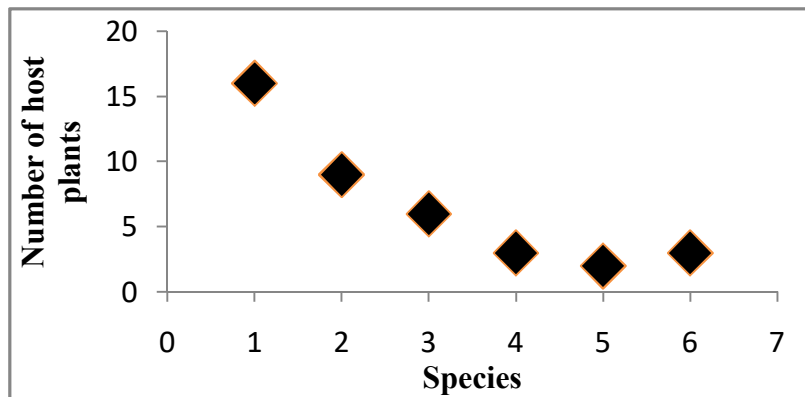


Figure 3: Graph showing the number of preference of host plants per species

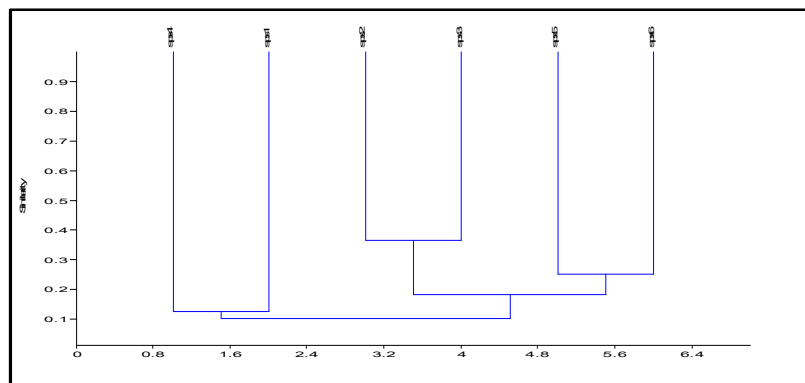


Figure 4: Dendrogram based on host plant selection of bagworm species

Other than the above similarity there is a wide variety in the plants inhabited by the different species which is reflected in the dendrogram (Fig. 4) indicates that based on the host selection Sp 2 and Sp 3 are most similar (approx 37%) followed by Sp 5 and Sp 6 (25%). Sp4 and Sp 1 was least similar (13%).

Of the 27 host plants recorded, (Fig. 3) Sp 1 was recorded on the most number of host plant species (16 host plants) followed by Sp 2 (9 host species), Sp3 (6 species), Sp 4 and 6 (3 each) and Sp 5 (2 species).

Conclusion

We observed a wide range of polyphagy at interspecific and intraspecific level among the six species of bagworms which indicates high potential as pests and also points at strategies evolved to avoid competition by species which share similar geospatial and climatic ranges. The dendrograms generated clearly indicate very low similarity based on host plant selection but high similarity in based on the climatic and geographical ranges of these moths. Further studies based on prolonged and extensive field work are needed to fix the habitat ranges of these moths.

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BAG MORPHOLOGY OF COMMONLY OCCURRING BAGWORMS (FAMILY: PSYCHIDAE) IN KERALA - A TAXONOMIC TOOL

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ABSTRACT

Bag making is the most prominent characteristic of bagworms (Family: Psychidae). They construct bags using different materials like silk threads, plant twigs, leaves, thorns and other plant parts. It has been observed that each species of bagworm has a unique type of bag making behaviour and bag architecture on which many studies have not been conducted. From the taxonomic point of view, it is an important to classify bagworms to at least generic level according to their bag architecture because the unique life cycle of these insects wherein the female never emerges out of the bag and the male moth has a very short lifespan after emergence. This study describes and compares the morphology of three different bags of *Eumeta* sp., *Brachycyttarus* sp., and *Pteroma* sp. *Eumeta* sp. construct bags with sticks ranging around 5cm length arranged in a circular manner. *Brachycyttarus* nests were characterized by mixed material (leaves embedded in silk) to form a cone-like bag. *Pteroma* sp. had a similar bag to *Brachycyttarus*, but differed in the attachment thread and size.

Key words: Psychidae, bagworms, *Eumeta*, *Brachycyttarus*, *Pteroma*

INTRODUCTION

A nest is a structure built by certain animals to hold its eggs, its offspring, or occasionally the animal itself. Although nests are most closely associated with birds, members of all classes of vertebrates and some invertebrates construct nests. Bag making is the most prominent characteristic of bagworms and they construct bags using different materials like silk threads, plant twigs, leaves, thorns and other plant parts. They complete their life cycle inside their bags. The bagworm family has 1350 described species from 241 genera globally (Nieukerken et al., 2011) except Antarctica. Hampson (1892) listed 36 species from British India including Sri Lanka and Myanmar and is supposed to be the oldest record of bagworms from India. A recent study (Sobczyk, 2011) indicates the presence of 106 species belonging to 34 genera in India. Bagworms build their bags by using different materials such as plant twigs, leaves, thorns, flowers and other plant parts over a silky bag. They complete their life cycle inside their bags and only the male insect hatched as a winged moth from the bag, most of the females are apterous and persist as an egg sac inside the bag (Rhainds, et.al., 2009). The documentation of this insects are very significant because of being polyphagous, several species are defoliating pests of cultivated crops causing moderate to severe economic damage (Basri, 1993).

In Southeast Asia, there are many records of serious damage caused by bagworms in palm plantations and other plants of economic importance were reported (Shah et al., 2016).

Even though bagworms have not manifested themselves as a major pest in Kerala, there is always a chance that they may become a pest due to unwise agroforestry practices, habitat disturbances, and climate change. There is a paucity of recent scientific literature from Southern India based on comprehensive studies of bagworms. This study is a preliminary attempt for analyzing the morphological characteristics of the bags of commonly occurring bagworms in Kerala.

MATERIALS AND METHODS

The bagworm bags were collected from human inhabited/ altered areas in Kerala state India. The bags were collected from the host plants by handpicking method and the collected bags were measured and recordings of all morphological characters made. Bags were then reared inside the rearing bottle for further examinations and studies. When a male moth hatched out of a bag, it was identified till generic level using standard identification keys.

RESULT AND DISCUSSION

The bags were basically made up of silken threads produced by the animal itself. Other materials used were, leaves, twigs, thorns, flowers and other plant materials. Each genus used specific materials for their bag making and showed a unique pattern of bag making behaviour. Morphological characters of the bags of the three genera are as follows.

Eumeta sp. - *Eumeta* species was the most commonly occurring bagworms from almost all the surveyed areas. Almost cylindrical in shape and made up of plant twigs on the surface of a silky bag made by the larvae. The sticks are arranged in a circular pattern and it gives the bag to a cylindrical shape. Most of the bags show a common characteristic of possessing a proportionately longest stick. Larvae renovate or increasing its bag size by using longest sticks at each progressing instars. Most of the sticks used for the bag making are from their host plant.

Brachycyttarus sp. - Bag of this species is almost cone shaped, whitish cream coloured and has two openings at the anterior and posterior ends. The bag is a tough leathery structure made up of silky threads and small pieces of leaves. A mature larval bag has a measure of 19.5 mm and have 9.4 mm circumference at the anterior end and 10.4 mm at the posterior. The head capsules of each instar larvae are attached to the neck region the bag from which it is deduced that the number of instars is 7 or 8.

Pteroma sp. - It is a relatively small sized bag. The main characteristic of this type is the long thread on the anterior part of the bag which is longer than the bag and it helps to attach the bag to the host plant. The average length of the bag is 9 mm. The shape is a mixture of cylindrical cone. The bag surface is almost smooth and sparsely covered with small pieces of leaves.

Table 1. Main characteristic features of bags

Sl. No.	Genus	Bag characters		
		Colour	Length/width (mm)	Features
1	<i>Eumeta</i> sp.	Dark brown	46/32	Cylindrical, made up of twigs, have one long stick
2	<i>Brachycyttarus</i> sp.	Whitish, creamy white with brown spots	20/19	Conical, leathery smooth, made up of mainly tough silky material and pieces of leaves
3	<i>Pteroma</i> sp.	Brownish	9/2.5	Small compared to others, almost cylindrical, smooth surface with bits of leaves and possess long thread anteriorly

The bag of *Eumeta* sp. is the largest of the three and has at least one stick which is disproportionately longer than the remaining sticks in the case and exhibits a rhythmic pattern in the arrangement of these materials around its bag. At each instar, it expands the size of its bag by discarding the older materials, such as thorns and/or twigs and attaches newer and bigger materials. This phenomenon has been referred to as case-renovation behaviour (Agrawal & Pati, 2003). Bags of the other two species have not been described in detail before. The unique feature of the bag of *Brachycyttarus* sp. is the attachment of the head capsules of each instar larvae are attached to the neck region the bag from which the number of instars may be deduced as 7 or 8. *Pteroma* sp. has the smallest bag with a long attachment thread.

CONCLUSION

The bag morphology of bag worms is important because it helps the farmer and common man to correctly identify the elusive pest with an obscure life cycle. The importance of the phytophagous insect bagworms as a pest has been underestimated and the number of studies from human habitations is non-existent. This study, a preliminary attempt to identify the bags of commonly found bagworm species clearly indicates that bag morphology is a crucial taxonomic tool.

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Sl. No.	Data Field	Data specification
1.	NBA Reference	—
2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R. INV. 25277
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Acanthopsyche alstoni</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Acanthopsyche</u>
	Subgenus	
	Species	<u>A. alstoni</u>
	Subspecies	
	Author and Date	Watt & Mann, 1903
	No. of Specimens	01
	Locality	Arthani
	Taluk	Aluva
	District	Ernakulam
	State	Kerala
	Date of Collection	13-11-2021
	Collected by	Usha AU
	Determined by	Thomas Sobczyk
	Type Category	Neotype
6.	Name and address of the depositor	Usha AU Dept Zoology St. Thomas College, TCR
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Acanthopsyche alstoni</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Acanthopsyche</u>
	Subgenus	
	Species	<u>A. alstoni</u>
	Subspecies	
	Author and Date	Watt & Mann, 1903
	No. of Specimens	01
	Locality	Athani
	Taluk	Aluva
	District	Ernakulam
	State	Kerala
	Date of Collection	01-12-2021
	Collected by	Usha. AU
	Determined by	Thomas Sobczyk
	Type Category	Neotype
6.	Name and address of the depositor	Usha. AU Dep. Zoology, St. Thomas college, Tr
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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1.	NBA Reference	—
2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R. INV. 25279
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Eumasia thomasi</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	psychidae
	Genus	<u>Eumasia</u>
	Subgenus	
	Species	<u>E. thomasi</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Roby, Jose, 2022
	No. of Specimens	01
	Locality	Koviloor - Vattavada
	Taluk	Devikulam
	District	Idukki
	State	Kerala
	Date of Collection	11-07-2022
	Collected by	Usha AU
	Determined by	Thomas Sobczyk
	Type Category	Holotype
6.	Name and address of the depositor	Usha AU Dept. Zoology St. Thomas college
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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1.	NBA Reference	—
2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R. INV. 25280
3.	Name and Address of the Designated Repository	ZSI/WGRC, Kozhikode
4.	Taxon / Species Name	<u>Eumasia thomasi</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Eumasia</u>
	Subgenus	
	Species	<u>E. thomasi</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Roby & Jose, 2022
	No. of Specimens	01
	Locality	Koviloor - Vattavada
	Taluk	Devikulam
	District	Idukki
	State	Kerala
	Date of Collection	10-07-2022
	Collected by	Usha. A U
	Determined by	Thomas Sobczyk
	Type Category	Paratype
6.	Name and address of the depositor	Usha. A U Dept. Zoology St. Thomas College
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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1.	NBA Reference	—
2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R. INV. 25282✓
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Capulopsycha keralensis</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Capulopsycha</u>
	Subgenus	
	Species	<u>C. keralensis</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Roby, Jose, 2023
	No. of Specimens	01
	Locality	Narayanpara
	Taluk	Udumbanchola
	District	Idukki
	State	Kerala
	Date of Collection	16-12-2021
	Collected by	Usha. AU
	Determined by	Thomas sobczyk
	Type Category	Paratype
6.	Name and address of the depositor	Usha. AU Dept. of Zoology, St. Thomas College, ICR
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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1.	NBA Reference	—
2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R.INV.25283
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Eumasia venetica</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Eumasia</u>
	Subgenus	
	Species	<u>E. venetica</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Rohy, & Jose, 2023
	No. of Specimens	01
	Locality	Nariyampara
	Taluk	Uthupanchala
	District	Idukki
	State	Kerala
	Date of Collection	28-10-2022
	Collected by	Usha. AU
	Determined by	Thomas Thom Sobczyk
	Type Category	Holotype
6.	Name and address of the depositor	Usha. AU Dept. Zoology, St. Thomas college, Kozhikode
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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2.	Repository Reference Number / Registration Number	ZSI/WGRC / I.R. INV. 25284
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>Eumasia venefica</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>Eumasia</u>
	Subgenus	
	Species	<u>E. venefica</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Roby & Jose, 2023
	No. of Specimens	01
	Locality	Narayanpara
	Taluk	Udumbanchola
	District	Idukki
	State	Kerala
	Date of Collection	19-10-2022
	Collected by	Usha AU
	Determined by	Thomas Sobczyk
	Type Category	Paratype
6.	Name and address of the depositor	Usha AU St. Thomas college Thrissur
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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2.	Repository Reference Number / Registration Number	ZSI/WGRC/I.R. INV. 25281
3.	Name and Address of the Designated Repository	ZSI-WGRC, Kozhikode
4.	Taxon / Species Name	<u>CapuloPsyche keralensis</u>
5.	Collection Details	
	Phylum	Arthropoda
	Class	Insecta
	Order	Lepidoptera
	Family	Psychidae
	Genus	<u>CapuloPsyche</u>
	Subgenus	
	Species	<u>C. keralensis</u>
	Subspecies	
	Author and Date	Usha, Sobczyk, Roby, & Jose, 2023
	No. of Specimens	01
	Locality	Nariyampara
	Taluk	Idumbanchola
	District	Idukki
	State	Kerala
	Date of Collection	28-11-2022
	Collected by	Usha. A U
	Determined by	Thomas Sobczyk
	Type Category	Holotype
6.	Name and address of the depositor	Usha. A. U Dept. Zoology, St. Thomas College, Thrissur.
7.	Date of Receipt	30.10.2023
8.	Date of Acknowledgement	30.10.2023

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