STUDIES ON PREDATORY MITES INHABITING DIFFERENT STORED PRODUCTS IN NORTH KERALA

Thesis submitted in partial fulfillment of the requirements for the award of Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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UNDER THE GUIDANCE OF

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DECLARATION

I hereby declare that the work presented in the thesis entitled "**STUDIES ON PREDATORY MITES INHABITING DIFFERENT STORED PRODUCTS IN NORTH KERALA**", is based on the original work done by me under the guidance of **Dr. Sachin P. James**, Head and Assistant Professor, P.G. & Research Department of Zoology, **Malabar Christian College, Calicut**, and has not been included in any other thesis submitted previously for the award of any degree. The contents of the thesis are undergone plagiarism check using **iThenticate** software at C.H.M.K. Library, University of Calicut, and the similarity index found within the permissible limit. I also declare that the thesis is free from AI generated contents.

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NEERAJ MARTIN

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ABSTRACT

Title: STUDIES ON PREDATORY MITES INHABITING DIFFERENT STORED PRODUCTS IN NORTH KERALA

India, a major producer and consumer of agricultural commodities, continues to face challenges in managing stored product pests in warehouses and other storage environments. Despite growing awareness of chemical risks, fumigants remain widely used, raising concerns for health, environment, and trade compliance. In this context, there is a growing need to explore sustainable and biologically driven pest control alternatives. Predatory mites represent a promising but underutilized resource in stored-product pest management. However, limited studies in tropical storage conditions, lack of rearing methodologies, and a narrow taxonomic focus have hindered their practical application. The present study addresses these gaps through a holistic investigation into the diversity, biology, and applied potential of predatory mites from storage habitats in North Kerala, offering new insights and tools for future biocontrol strategies. This study provides a comprehensive assessment of the diversity, biology, and biocontrol potential of predatory mites associated with stored products in North Kerala, India. A total of 28 predatory mite species, representing 19 genera, 13 families, and 2 orders, were identified through surveys conducted across six districts and 61 storage facilities, including government-operated warehouses. Several taxa were newly recorded from India, including the description of two new species viz., *Acaropsella strioreticulata* and *Fessonia indica*. These findings expand the known distribution of beneficial mites and emphasize their potential roles in integrated pest management.

The developmental biology of the dominant predatory mite species *Cheyletus malaccensis* was investigated under varying temperature (25°C, 29°C, and 33°C) and relative humidity (70%, 80%, and 90%) conditions. Results showed that 25°C with 70–80% RH favoured higher fecundity, while 29°C with 80% RH promoted greater survival and faster development. Feeding trials revealed clear predator-prey stage specificity, with adult females demonstrating the highest predation efficiency against *Suidasia nesbitti*, particularly targeting its early life stages. To address methodological limitations in mite rearing, a custom 3D-printed Petri dish was designed and tested. This escape-proof, hygienic, and reusable system facilitates observational studies and has broad applicability across stored-product mite research.

The study also established a novel mass-rearing protocol for *C. malaccensis*, achieving a 36.5-fold population increase in 30 days under controlled conditions. Importantly, this research marks the first standardized method for mass-rearing *C. malaccensis*, a species not yet available commercially despite its global distribution and biocontrol potential.

സംഗ്രഹം

ശീർഷകം: ഉത്തരകേരളത്തിലെ വിവിധ സംഭരണ ഉത്പന്നങ്ങളിൽ അധിവസിക്കുന്ന പ്രിഡേറ്ററി മൈറ്റുകളെ കുറിച്ചുള്ള പഠനം

ഇന്ത്യ കാർഷിക ഉൽപ്പന്നങ്ങളുടെ പ്രധാന ഉത്പാദന-ഉപഭോകൃത രാജ്യമാണ്. വിളവെടുത്ത കാർഷിക ഉൽപന്നങ്ങൾ സംഭരണശാലകളിൽ വെച്ച് പല വിധ കീടബാധയ്ക്ക് വളരെയധികം വിധേയമാണ്. വർധിച്ചു വരുന്ന കീടങ്ങൾക്കെതിരെയുള്ള രാസ കീടനിയന്ത്രണ രീതികളും തുടർന്നുണ്ടാകുന്ന ആരോഗ്യ-പാരിസ്ഥിതിക പ്രത്യാഘാതങ്ങളും വെല്ലുവിളികളും വളരെ പ്രാധാന്യമേറിയ ഒരു വിഷയമാകുന്നു. അതിനാൽ, സുസ്ഥിരവും ജൈവപരവുമായ വ്യത്യസ്ത കീടനിയന്ത്രണ മാർഗങ്ങൾ തേടേണ്ടതിന്റെ ആവശ്യകത വർധിക്കുന്നു.

സംഭരിച്ചു വെച്ചിട്ടുള്ള ഭക്ഷ്യധാന്യങ്ങളിലെ കീടനിയന്ത്രണത്തിൽ പ്രിഡേറ്ററി മൈറ്റുകൾ ഫലപ്രദമാണെന്ന് കൃത്യമായി തെളിയിച്ചിട്ടുണ്ടെങ്കിലും, മതിയായ ഗവേഷണങ്ങളുടെ കുറവും വ്യാവസായികാടിസ്ഥാനത്തിൽ അവയെ വിജയകരമായി വളർത്തിയെടുക്കുന്നതിനുമുള്ള മാർഗങ്ങളുടെ അഭാവവും പ്രായോഗിക ഉപയോഗത്തെ വളരെയധികം പരിമിതപ്പെടുത്തുന്നു. വടക്കൻ കേരളത്തിലെ സംഭരണശാലകളിൽ നടത്തിയ ഈ പഠനം, പ്രിഡേറ്ററി മൈറ്റുകളുടെ ജൈവവൈവിധ്യം, ജൈവശാസ്ത്രം, ജൈവനിയന്ത്രണ സാധ്യതകൾ എന്നിവ വിലയിരുത്തി. 6 ജില്ലകളിലെ 61 സംഭരണസ്ഥാപനങ്ങളിൽ നടത്തിയ സർവേയിലൂടെ 19 ജനുസ്സുകളിലും 13 കുടുംബങ്ങളിലുമായി ഉൾപ്പെടുന്ന 28 പ്രിഡേറ്ററി മൈറ്റ് സ്പീഷീസുകൾ കണ്ടെത്തി. ഇതിൽ രണ്ട് പുതിയ സ്പീഷീസുകളുടെ വിവരണവും, ഇന്ത്യയിൽ ആദ്യമായി രേഖപ്പെടുത്തിയ ചില ജനുസ്സുകളും ഉൾപ്പെടുന്നു.

ഏറ്റവും സാധാരണവും വളരെ ഫലപ്രദവുമായ *കെലിറ്റസ് മലക്കെൻസിസ്* എന്ന പ്രിഡേറ്ററി മൈറ്റിന്റെ വികസനജീവശാസ്ത്രം വ്യത്യസ്ത താപനില ആർദ്രത നിലകളെ ആസ്പദമാക്കി പഠനവിധേയമാക്കി പരിശോധിച്ചു. 25°C താപനിലയും 70-80% ആർദ്രതയും ചേർന്നു വരുന്ന അവസ്ഥയിൽ കൂടുതലായ ജനനക്ഷമതയും, 29°C താപനിലയും 80% ആർദ്രതയും ചേർന്നു സംജാതമാവുന്ന മറ്റൊരു അവസ്ഥയിൽ വേഗത്തിലുള്ള വളർച്ചയും ഉയർന്ന ജീവനിരക്കുമാണ് കണ്ടെത്തിയത്. *കെലിറ്റസ് മലക്കെൻസിസ്*, കീട സ്വഭാവമുള്ള *സുയിഡേഷ്യ നെസ്ബിറ്റി* എന്ന മൈറ്റിന്റെ പ്രാരംഭഘട്ടങ്ങളെ വേട്ടയാടുകയും ഉയർന്ന പ്രിഡേഷൻ നിരക്കും കാഴ്ചവെച്ചു. ഇത്തരത്തിലുള്ള പ്രിഡേറ്ററി മൈറ്റുകളുടെ ഫലപ്രദമായ ഗവേഷണത്തിനായി അവയെ നിയന്ത്രണവിധേയമായി വളർത്തിയെടുക്കുവാൻ ത്രിമാന പ്രിന്റ് ചെയ്തെടുത്ത, പുനരുപയോഗ യോഗ്യമായ പെട്രി ഡിഷ് വികസിപ്പിച്ചു. നിയന്ത്രിത സാഹചര്യങ്ങളിൽ 30 ദിവസത്തിൽ 36.5 മടങ്ങ് ജനസംഖ്യ വർദ്ധനവ് കൈവരിക്കുന്നതിന് പ്രാപ്തമായ മാസ്സ് റെയറിങ് രീതികൾ *കെലിറ്റസ് മലക്കെൻസിനെ* അടിസ്ഥാനമാക്കി പരീക്ഷണശാലയിൽ വിജയകരമായി വികസിപ്പിച്ചെടുത്തു. ലോകവ്യാപകമായി പ്രസ്തുത മൈറ്റ് സ്പീഷീസ് കാണപ്പെടുന്നുണ്ടെങ്കിലും, വാണിജ്യാടിസ്ഥാന രൂപത്തിൽ ഇതുവരെ ലഭ്യമല്ലാത്ത ഈ സ്പീഷീസ് ഉപയോഗിച്ചുകൊണ്ടുള്ള ജൈവ നിയന്ത്രണ സാധ്യതകൾ പഠനം തെളിയിക്കുന്നു.

CHAPTER I

INTRODUCTION

1. INTRODUCTION

Nature is incredibly astonishing in its diversity and complexity. Every living organism strives to adapt to the challenging ecological conditions on earth, and undergoes the endless process of evolution. Many prominent species of the animal kingdom captivate us with their attractive morphological features like the antlers of deer, the plumage of peacocks, the tusks of elephants, the iridescent shine of beetles, the mane of lions, the unique stripes of zebras, and the fins of whales. These fascinating traits are more conspicuous and evoke enthusiasm among people. However, when it comes to microscopic organisms, the morphological attributes are equally prominent, but it is less discussed. The complex beauty and adaptability of these small life forms are bewildering in the intricate network of life. From this perspective, the acari, commonly referred to as mites and ticks, are often underappreciated. Their significance is primarily confined to the research community; beyond that, these small arachnids remain unexplored by the general public and deserve greater attention among non-specialists. People are often concerned about the negative aspects of these organisms, such as their role as vectors and the diseases they transmit, but the benefits they provide are always overlooked or inadequately investigated.

Mites belong to subclass Acari within the class Arachnida which come under Arthropoda, the largest and most diverse phylum in the animal kingdom. Subclass Acari currently comprises approximately 55000 described species from two superorders, namely Parasitiformes and Acariformes (Krantz and Walter, 2009). Among these, order Mesostigmata under Parasitiformes and order Trombidiformes under Acariformes encompass important species of predatory mites. Meanwhile the order Sarcoptiformes, also classified under Acariformes, particularly the members belonging to the cohort Astigmata, constitutes the prominent pest mite community.

The morphological characteristics of mites diverge significantly from those of insects. Notably, mites lack a distinct head, thorax, and abdomen, as well as antennae and wings. Mites possess four pairs of legs compared to three pairs of legs of insects and their body is divided into two specialized segments, namely the gnathosoma and idiosoma, each serving distinct functional purposes.

Mites are widely distributed on the planet, thriving in every ecological habitat on earth. They are found in extreme cold environments, hot deserts, deep within soil layers, freshwater as well as marine ecosystems. Mites assumes various ecological roles as, parasitic, phoretic, mycophagous, saprophagous, phytophagous, or predatory. Their body and mouthparts have evolved accordingly to thrive in different niches. Mites are mostly fee living however, they form associations with insects, centipedes, molluscs, amphibians, reptiles, birds, and mammals. They frequently inhabit human skin and hair follicles, occasionally causing allergic reactions, dermatitis, and diseases such as scabies caused by *Sarcoptes scabiei*. Dust mites of the genus *Dermatophagoides* cause serious respiratory diseases to humans. Dogs are more frequently affected by mite infestations.

Over three hundred acarine species have been reported in association with human dwellings and stored product environments (Montealegre et al., 2002). Pest mites infest different stored products such as cereals, pulses, dried nuts and fruits, oil seeds, dried fish, spices etc., causing severe damage. Eventually, these products become unsuitable for human and animal consumption. Additionally, mites affect germination by damaging the endosperm either partially or completely. They also deplete essential nutrients such as proteins, amino acids, carbohydrates, vitamins of the stored products leading to further economic loss (Nangia, 1986; Gupta, 2012). The stored products build an ecosystem where different intraspecific as well as interspecific interactions take place. The stored cereals and pulses with 13% or more moisture content are more prone to mite infestation (Solomon, 1967). Furthermore, excretion of mites attracts other potential insect pests.

India is basically an agriculture-oriented country and has to feed 1.46 billion people which not only demands high productivity in agriculture but also proper storage and preservation to protect post harvested crops from spoilage by pests including insects, rodents and mites. Stored products such as cereals, pulses, spices plays an important role to providing balanced nutritional diet. Good crop production and proper storage ensures improved economic condition of farmers, and merchants. Besides it enhances the export potential and nutritional security to the people.

According to the statistical reports of the Ministry of Agriculture and Farmers Welfare, (2023), India is one of the world's largest producers of cereals, particularly, rice and wheat. India holds the second position in rice production and the second in wheat production, significantly contributing to global food security. India is the largest producer and consumer of pulses globally, contributing around 25-30% of global production. The primary pulse varieties cultivated include chickpeas, lentils, and pigeon peas. Furthermore, India produced over 330 million metric tons of food grains, 27 million metric tons of pulses in 2022-2023.

Indian spices are renowned for their aroma, flavour, health, and tradition. They are widely used in many dishes, medicine, and other industries. India holds a dominant position, contributing approximately 75% of the world's spice production and ranking as the largest consumer and exporter. The country cultivates a wide variety of spices, including pepper, cloves, cardamom, cinnamon, nutmeg, fennel seeds, cumin, chilli, and turmeric. According to statistics of spices board of India, 2022-23, India exported spices worth 4 billion US dollars, dominating the global spice trade.

Despite remarkable achievements in agricultural production, India confronts significant losses due to improper storage and post-harvest mismanagement. According to the recent reports by Indian Council of Agricultural Research (ICAR), Food and Agriculture Organization, Spices Board India, and National Food Security Mission, India encounters significant post-harvest losses in economically important agricultural commodities due to various factors including insect and mite infestations, fungal contamination, rodent attack, moisture exposure, fungal growth, improper storage practices and infrastructures. Annual losses account for 6-10% for cereals, 8-12% for pulses, 5-7% for spices, and 10-15% for oilseeds. Such losses threaten and impact food security and create economic burdens for both farmers and the broader agricultural industry.

Mites have evolved various digestive adaptations, particularly the presence of numerous digestive enzymes, which play a pivotal role in their feeding abilities. Stored products inhabiting mites have developed a diverse array of enzymes, comprising carbohydrases, proteases, phosphatases, and lipases according to their specialized diets and habitats (Akimov, 1973; 1985, Hubert et al., 2004). An interesting example is the scabies causing mite *Sarcoptes scabiei*, which possesses an aspartic protease with the enzymatic potential to break down and digest human blood proteins including, haemoglobin, serum albumin, fibronectin and fibrinogen (Mahmood et al., 2013).

Mites are often found associated with harmful and damaging storage fungi, they together cause allergy to the warehouse workers handling stored products, farmers and other agricultural workers. Mite species from the family Glycyphagidae are commonly found in stored products, having significant clinical importance and they are infamous for eliciting immune responses (Perez et al., 2022).

Apart from the damaging effects of pest mites, there are also many beneficial species. Mites from the order Oribatida play important role in the maintenance of soil fertility and biological control of pests. Many oribatids exhibit varying feeding behaviours, which in turn facilitate decomposition and humification, and numerous species exhibit different pH level preferences, making them effective biological indicators for detecting soil acidification (van Straalen, 1997). In contrast to the beneficial roles, there are many harmful phytophagous mite species belonging to families such as Tetranychidae, Eriophyidae, Tenuipalpidae, and Tarsonemidae, which severely infest crops and lead to significant yield losses in agricultural fields. After confronting significant damage caused by mites in the field, agricultural commodities are transported to warehouses, where they face the threat of secondary mite infestations. Thus, at every stage of production, there is a persistent risk of mite infestation.

Regarding the stored product ecosystem, over 100 species are known to be associated with stored products (Hughes, 1976). The primary families of stored-product mites, having pest status, include Acarididae, Glycyphagidae, Chortoglyphidae, and Carpoglyphidae (Hubert, 2012). Among these, *Acarus siro*, *Tyrophagus putrescentiae* and *Lepidoglyphus destructor* are the most frequent and abundant acarine pest species.

To confront, manage, and mitigate pest infestations, chemical pesticides and fumigants are extensively used worldwide. Even today, on a worldwide basis, the control of pests in the food industry and storage facilities is heavily reliant on the use of organophosphate pesticides, despite rising apprehensions and questions about their hazardous environmental and health impacts (White and Leesch, 1996). The extensive use of synthetic organic pesticides to manage target pests adversely affects non-target organisms across various trophic levels (Dejan et al., 2011). Excessive and improper use of chemical pesticides can lead to several adverse effects, including the elimination of natural predatory organisms, the development of pesticide resistance in pest populations, accumulation of residues in harvested agricultural products, and potential risks to human health (Muraleedharan, 1995; Marcic et al., 2011).

Pesticide resistance among acarines is an alarming concern. Organic phosphates have been found to inhibit the enzyme acetylcholinesterase in mites and ticks (Errampalli and Knowles, 1991; Roulston et al., 1966). However, some mites have evolved resistance through an altered acetylcholinesterase enzyme (Nolan and Roulston, 1979), and this serves as a primary resistance mechanism. Tetranychid mites, such as *Tetranychus urticae*, possess some modifications in their acetylcholinesterase, which exhibit diminished sensitivity to certain organophosphates (Helle and Sabelis, 1985). Similarly, widespread resistance to pirimiphos-methyl, and chlorpyrifos-methyl, has been documented in *Acarus siro* populations (Starzewski, 1991; Prickett, 1997).

Across the world, particularly consumers in developed countries are showing a strong preference for agricultural products cultivated with minimal or no chemical treatments. Quarantine inspection protocols have been strengthened to ensure that no pesticide contamination occurs in imported or exported goods. Many warehouse owners are conscious of health risks linked to the over application of chemicals, are now adopting natural predators and organic pesticides. As some organophosphates are no longer permitted for use in food industry pest control, finding alternative solutions has become a priority (Collins 2006). In this context, plant-derived acaricides contain active compounds with high efficacy for the suppression of stored-product mites (Czajkowska 1972).

Biological control with natural enemies such as predatory mites, represents a sustainable and eco-friendly alternative to toxic chemical control measures. Seventeen species of predatory mites across four families namely, Phytoseiidae, Laelapidae, Macrochelidae, and Cheyletidae are now commercially available and widely used in augmentative biological control. Among these, majority of predatory mite species belong to the family Phytoseiidae, with twelve species (Knapp et al., 2018). These predatory mites are capable of attacking and devouring a wide range of pest mites nevertheless, field studies on their effectiveness are meagre, and demanding further research to validate the outcomes (Pozzebon et al., 2015).

The genus *Cheyletus* comprises twenty nine described species, all of which are potent acarophagous predators frequently found in stored products. Among these, *Acaropsis docta*, *Cheyletus eruditus*, and *C. malaccensis* have proven to be efficient predatory acarine species for the biological control of mite pests in stored products (Gupta, 2001, 2003).

A significant amount of research has been conducted worldwide on mites associated with stored food products. Despite being the seventh-largest country and one of the most agriculturally significant nations, India has made limited progress in this field of research, with studies on mite fauna. While some research has been carried out in some states viz. Haryana, Punjab, Himachal Pradesh, Uttar Pradesh, West Bengal, Odisha and Karnataka, the majority of other states remain largely unexplored in this regard

Agriculture in Kerala is distinguished by small landholdings and has witnessed a pronounced structural transition from food crops to cash crops in recent years. Approximately

90% of the net cropped area is dominated by profitable plantation crops such as rubber, cashew, coconut, tea, coffee, and cardamom. Despite this, traditional and subsistence food crops like rice, pulses, minor millets, and tapioca account for only 10% of the cultivated area. Recent reports indicate that Kerala continues to be a food deficit state, highly dependent on other states for the supply of food grains (Maneesh and Deepa, 2016). The returns generated from commercial crops and the non-agricultural sector are being allocated to import food commodities from other states. The growing demand for food commodities has resulted in a decline in self-sufficiency of Kerala, indicating a further deterioration in the coming years. (Shinoj, 2015).

The rising dependence on imported food commodities, rather than cultivating essential food crops domestically, highlights the need for proper storage infrastructure and pest management. North Kerala, particularly the Malabar coast, has been renowned for its rich history of trading, dating back to ancient times. Historically, the ancient Malabar port, Tyndis (now known as Ponnani, Tanur, and Kadalundi-Vallikkunnu), played a pivotal role in fostering trade ties with the Roman Empire. Presently, North Kerala is mainly prioritizing importing and storing food commodities. The region features many small-scale, privately owned storage facilities inside large marketplaces, as well as large-scale warehouses owned by the Government of India, including the Food Corporation of India (FCI), which stores and reserves hundreds of thousands of metric tonnes of rice, wheat, and other essential grains. Considering the significance of these storage hotspots, it is essential to minimize the application of chemical pesticides and fumigants to ensure the health and well-being of consumers. In this context, research exploring biological control strategies gains significance, as these methods offer a sustainable and eco-friendly alternative to chemical control.

Taxonomic research plays a pivotal role in the accurate identification and diagnosis of species, which is a critical factor in the success of biological control programs. Proper understanding about the diversity of predatory mites is very crucial and important as it will help to track and manage the pest outbreaks. Besides, these information can be effectively used in confronting the emergence of new pest species. The present study primarily focused on surveying and documenting the predatory mite fauna associated with stored products in North Kerala, in addition to this, the research also aims to clearly evaluate the predatory potential and feasibility of the predatory mite species *Cheyletus malaccensis* for controlling the common storage pest mite species, *Suidasia nesbitti*. Furthermore, the feeding and breeding biology of *C. malaccensis* has been studied under varying temperature and humidity conditions. This research also includes efforts to mass rear the species for use in pest management strategies.

Objectives of the study

1. To study the faunal diversity of predatory mites inhabiting different stored products in North Kerala.

2. To give detailed illustrations, descriptions of new species/genera, re-description of little-known taxa and to record the systematics of predatory mites of different families with keys.

3. To trace the breeding biology of a potent predatory mite species at different temperatures and humidity levels, and to evaluate its feeding potential at optimum temperature and humidity.

4. To develop a mass-rearing methodology for the potential predatory mite in the laboratory.

CHAPTER II

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. Part I- Taxonomy

Research on predatory mites inhabiting stored products in India is significantly limited. Existing Indian publications are primarily survey-based, with a few doctoral studies addressing bioecology, damage assessment, and climatic influences, but often lacking detailed taxonomic analyses. It is important to consider that the same pest and predatory mites found in stored –

products are also prevalent in other habitats. Although this overlap highlights their ecological versatility, it is impractical to include all related studies in this review. Furthermore, the present study encompasses a wider scope, rather than concentrating exclusively on any particular family or genus. Therefore, this review focuses specifically on studies related to the exploration, diversity, and taxonomy of predatory mites inhabiting stored products, including their interaction with pest mites and their potential for pest mite control.

2.1.1 Research from abroad

Precise knowledge of the nature and mechanism of damage inflicted by pest mites is crucial for implementing preventative and control strategies in stored products. In this context, Solomon (1946) investigated the nature and extent of damage caused by Tyroglyphid mites to stored wheat. The study confirmed that mites cannot penetrate an intact seed coat, but observed that less than 10% of grains retain their intact seed coats. In laboratory settings, it was determined that mites consumed up to 3% of grain weight before dying, preferentially targeting the germ. The maximum consumption rate was 0.29% of grain weight per week. While higher temperatures and humidity increased consumption rates, lower temperatures and humidity prolonged mite survival, resulting in more overall damage. Mites consumed wheat germ flakes more rapidly, reducing its weight by 74-85%. Furthermore, the study proposed a visual damage assessment system, correlating mite density and time with grain weight loss.

As early as the mid twentieth century, researchers recognized the limitations and the detrimental impacts of fumigation and explored the potential of predatory mites as a promising biological control strategy in stored grain. Norris (1958) investigated the natural control of the grain mite *Acarus siro* by predatory *Cheyletus* species in stored imported wheat. The study found that *Cheyletus* species developed in a significant portion of wheat parcels after 12-18 months, often achieving dominance over other mites, particularly in late summer for bagged wheat and during winter for bulk grain when surface moisture was high. This natural control by *Cheyletus* species was comparable to, and sometimes superior to, fumigation with methyl bromide. Earlier fumigation negatively impacted *Cheyletus* species development, while lindane spraying indicated some evidence of favouring its development. The study also documented the effective elimination of *A. siro* and *Glycyphagus destructor* by *Cheyletus eruditus* in a bulk grain store, noting that *C. eruditus* populations increased faster in disturbed grain but achieved dominance first in undisturbed grain.

Pulpan and Verner (1965) studied mite infestations in Czechoslovakian stored grain, identifying *Acarus siro* and *Glycyphagus destructor* as the prevalent pest species. Recognizing the limitations of traditional fumigation methods, the authors explored biological control with the predatory mite *Cheyletus eruditus*. Observations revealed natural control instances leading to complete eradication of grain mites. The study examined eight grain storage facilities, with detailed observations from one main site and summarized findings from the remaining seven locations. Authors also investigated the influence of cleanliness and moisture content on mite development, demonstrating a significant increase in mite populations in unclean and moist wheat. Semi-operational trials with *C. eruditus* introductions were successful, leading to complete eradication of harmful mites. The study recommended collecting predatory mites from natural habitats and introducing them in spring or autumn at specific ratios for effective control.

Cunnington (1965) conducted an in-depth investigation of the common stored-product pest mite, *Acarus siro* and determined the precise temperature-humidity thresholds essential for its survival in stored grains and flour. The results explained the dominance of *A. siro* in storage facilities compared to its related species, providing crucial parameters for predicting pest outbreaks. The findings also have direct implications for biological control strategies, as predatory mites, specifically *Cheyletus* and *Blattisocius* species, exhibit temperature-dependent predation behaviors that must align with pest population dynamics. By quantifying the environmental limits of *A. siro*, Cunnington established a foundational framework for developing predator-based integrated pest management in stored products.

Solomon (1969) carried out detailed experiments on predator-prey interactions between *Cheyletus* and *Acarus* mites in stored wheat, emphasizing the significant influence of temperature and humidity. The study revealed that these environmental factors imposed distinct survival limits for both prey and predator, defining a range within which their interaction could occur. Within this range, different combinations of temperature and humidity determined the predator's ability to control prey populations, which could be mapped as a grid of humidity against temperature. The particular dynamics of this interaction were found to be habitat-dependent, with wheat grain serving as the model. Notably, *Cheyletus* demonstrated a relatively low responsiveness to prey population fluctuations and a high tolerance for food shortages. These traits contributed to a tendency towards relaxation interaction, marked by the elimination of prey followed by delayed predator starvation, prolonged by cannibalism and endurance.

Smith (1970) documented heavy mite infestations in farm grain stores across Cornwall, England, between 1963 and 1967, based on 36 farm advisory visits. The study revealed significant infestations in wheat, barley, oats, and animal feed stored in diverse environments. The dominant mite species associated with heavy infestations were *Acarus siro* and *Tyrophagus longior*, often accompanied by *Cheyletus eruditus, Glycyphagus destructor, Acarus farris,* and *Kleemannia plumosus*. Notably, *A. farris* and *T. longior* were frequently found in newly harvested grain during October and November, while *A. siro* infestations were more common in stores where farm-grown grain was mixed with feed from external sources.

To examine how stored-product mite populations fluctuate over time, Sinha and Wallace (1973) carried out an extensive study between 1959 and 1970, monitoring mite populations in stored wheat at two granary sites on farms in the Canadian Prairies. The study revealed similar population patterns between the two granaries. *Cheyletus eruditus* and *Acarus siro* exhibited periodic outbreaks in every 2-5 years, whereas *Androlaelaps casalis* and *Glycyphagus destructor* maintained relatively low populations throughout the storage period. *Tarsonemus granarius* populations increased with grain age and microfloral succession. The study identified several key factors regulating acarine population, particularly for *Acarus siro* and *Cheyletus eruditus*, including moisture, temperature, food availability, intrinsic rate of increase, seed damage and associated microflora etc.

Hughes (1976) published a book on stored product acarology which delineates the morphological diagnosis of approximately 100 species, encompassing predatory and pest mites from various orders and families. This work includes measurements of the idiosoma, concise biology, geographical distribution of each species. He included detailed illustrations and precise keys for genus and species identification. Hughes catalogued the specific stored products infested by each mite species and the nature of the damage they inflict. Even after five decades since its initial publication, his work remains a valuable resource for researchers.

Jeffrey (1976) explored the acarine fauna of 31 Scottish farms and recorded 70 mite species from 39 genera and 22 families across grain storage and handling areas. The study provided habitat, frequency and infestation intensity data. Jeffrey compared the findings with similar surveys in England, Wales, and Ireland. *Acarus farris* was identified as a persistent stored product pest mite, whereas *Tyrophagus longior* and *Glycyphagus destructor* were found to have no adverse effects on grain germination. The study also explored the potential for biological control of Tyroglyphid mites using predatory species *Androlaelaps casalis* and *Cheyletus eruditus*, indicating successful control.

Griffiths et al. (1976) undertook a survey to evaluate acarine populations within silo-stored grain on farms across England and Wales. Examination of 872 grain bulks revealed that approximately 90% were infested, with around 90 mite taxa identified. Among these, *Glycyphagus destructor* was the dominant species. Twelve species were consistently observed in all regions, demonstrating minimal geographical variation. However, *Acarus siro* and *A. farris* occurred less frequently in East Anglia compared to other areas. Mites were observed infiltrating damaged grains and feeding on fungal growth. Infestation levels varied significantly, with the heaviest concentrations in surface layers. The occurrence of *G. destructor* peaked in grain with 15-17% moisture, whereas no significant variation related to temperature was observed. Pre-harvest insecticidal treatments had no impact on mite frequency, and propionic acid treatment failed to eliminate mite infestation.

The faunistic survey conducted by Cusack et al. (1976) examined mite infestations in stored food commodities across the Republic of Ireland, analysing 766 samples from grain, flour, and storage residues. The study revealed a high overall infestation rate of 75.3%, significantly exceeding rates reported in other European surveys. *Acarus siro* was particularly prevalent in feedstuffs, whereas *Glycyphagus destructor* was widespread across various stored materials. Storage residues were identified as major sources of infestation, with farm-stored grain being especially vulnerable. A strong correlation was observed between moisture content and mite density, with higher moisture levels leading to increased mite populations. Additionally, an experimental component of the study demonstrated that mites from infested residues rapidly colonized clean grain, causing substantial weight loss. The research also highlighted the predatory role of *Cheyletus* species in regulating populations of *Acarus* and *Glycyphagus* mites.

Ždárková (1979) conducted a survey of mite fauna in food processing factories across Czechoslovakia from 1962 to 1978. In this long-term survey, 1560 samples were examined, leading to the identification of over ten thousand mite specimens from the Cheyletidae family, representing 10 distinct species. Among them, *Cheyletus eruditus* was the dominant species, followed by *C. malaccensis* and *C. trouessarti*. Several frequently found species, including *Cheyletus cruxor*, *Cheletomorpha lepidopterorum*, *Cheyletus hendersoni*, *Cheletia papillifera*, *Ker bakeri*, and *Grallacheles bakeri*, were recorded in Czechoslovakia for the first time. Furthermore, the study implied that, *Acaropsellina sollers* may be a junior synonym of *Acaropsellina docta*.

Sinha (1979) highlighted the role of Acari in the stored grain ecosystem. His findings revealed that approximately 50 mite species are associated with stored grain environments, particularly in temperate regions. These acarine communities are influenced by habitat interactions and primarily regulated by moisture, temperature, and substrate quality. Sinha also explored the ecological roles of these mites, designating them as energy transformers, granivores, predators, and scavengers, with species such as *Tyrophagus putrescentiae* and *Rhizoglyphus echinopus* demonstrating remarkable efficiency in grain energy transformation.

The predatory mite *Blattisocius tarsalis* was evaluated by Haines (1981) for its potential and effectiveness in controlling *Ephestia cautella*, a common stored-product moth. The study examined the biology of *B. tarsalis* under conditions of 27°C and 73% relative humidity, with emphasis on its developmental parameters and predation efficiency against the eggs of *E. cautella* and *Tribolium castaneum*. The research revealed that *B. tarsalis* preferentially preyed on *E. cautella* eggs, exhibiting a high potential rate of increase. The findings supported the hypothesis that fumigation negatively impacts the mite's effectiveness and suggested that modified control regimes could enhance natural control by *B. tarsalis*.

Managing pest mite outbreaks in storage environments poses a significant challenge to ensuring the safety and quality of stored products. All approaches in mitigating pest infestations hold significant importance. Ždárková and Horak (1990) emphasized the importance of disinfesting empty grain stores to prevent residual mite populations from infesting new grain. Emphasizing the advantages of biological control as an economical and eco-friendly strategy, a survey was conducted across 26 vacant agricultural warehouses in Czechoslovakia to assess mite diversity. Mites were detected in every facility, with astigmatid pest species occurring in 76.9% of the sites. The study demonstrated that releasing 2000-3000 *Cheyletus eruditus* predators per 100 m^2 significantly reduced acarid mite populations, revealing its potential as a preventive strategy.

Sinha and Kawamoto (1990) conducted a long-term study from 1978 to 1984 in Manitoba, Canada, focusing on the population trends and aggregation patterns of nine stored-grain mite species in two 7500 kilo gram wooden bin-stored oat batches, consisting of hulled (Random) and hulless (Terra) varieties. They found that Random oats harboured a greater number of mites than Terra oats. The grain-feeding mite *Lepidoglyphus destructor* was the most commonly detected species, whereas *Cheyletus eruditus* was found to be the predominant predatory mite. This investigation provided the first ecological insights into *Paratriophtydeus coineaui*. Both *Lepidoglyphus destructor* and *Tarsonemus granarius* were recognized as potential indicators of oat degradation, as their population levels corresponded with elevated fat acidity in the Terra oat variety. The distribution of mite species varied notably with depth within the grain mass, with certain species displaying interactions between depth and time. Most taxa demonstrated clumped (over-dispersed) distribution patterns. In addition, *T. granarius* and the predator pair *Blattisocius keegani–Androlaelaps casalis* exhibited different aggregation behaviors in the two oat types.

Mahmood (1992) carried out a faunistic survey to explore the mites inhabiting different stored cereal seeds in the central region of Iraq by sampling108 samples of rice, wheat and barley, and. The survey recorded 16 mite species, from 4 suborders, viz. Mesostigmata, Astigmata, Prostigmata, and Cryptostigmata, and reported 10 species that were not previously recorded in Iraq. Seasonal abundance was recorded for each cereal, with the highest species richness and individual mite counts observed in November on rice samples.

Shu Li and Fan (1997) carried out a survey on mites inhabiting stored food products from four provinces of China and recorded 79 species belonging to 25 families in 4 orders. Surveyed food products included grains, beans, dried fruits and vegetables, dried mushrooms, potato products, meat and fish products, and dairy products, etc. Additionally, they noted that *Tyrophagus putrescentiae* was the most abundant species. Furthermore, six other pest mite species, including *Carpoglyphus lactis, Suidasia nesbitti, Aleuroglyphus ovatus, Tarsonemus granaris, Lepidoglyphus destructor* and *Ctenoglyphus plumiger* were occasionally found in large numbers.

Ždárková and Feit (1999) revealed the feasibility of biological control of the pest mite species, *Acarus siro* on stored oilseeds (rapeseed, sunflower, and linseed) using the predatory mite *Cheyletus eruditus*. Suppressive biological control proved effective when the prey-to-predator ratio ranged from 1:20 to 1:50, and the initial *A. siro* infestation was below 500 specimens per kilogram. In empty oilseed stores, preventive releases of *C. eruditus* (2000 specimens per 100 m^2) successfully suppressed mite populations. Specifically, *A. siro* populations declined two months after *C. eruditus* introduction in all oilseeds, with sunflower seeds showing ratio-dependent decline rates.

Athanassiou et al. (2001) recorded the abundance, population density and distribution pattern of insect and mite species within stored wheat in central Greece. The study identified 12 mite taxa, including the predatory mites *Blattisocius tarsalis* and *B. keegani*, and the pest mites *Acarus siro* and *Lepidoglyphus destructor*, which were found to be the most abundant mite species. The research methods involved sampling wheat from a flat storeroom containing approximately 90 tons of grain, divided into central and peripheral zones. Population trends were monitored over an eight-month period, from June 1999 to February 2000, revealing peak densities of both insects and mites during the months of September and October.

Eliopoulos and Papadoulis (2001) expanded the known cheyletid mite fauna of Greece by reporting 5 species, viz., *Acaropsis sollers*, *Cheletomorpha lepidopterorum*, *Cheyletus aversor*, *Cheyletus trouessarti*, and *Cheyletus trux*. Apart from these new reports, they described and illustrated a new species of predatory mite, viz., *Chelacheles hellenicus*, obtained from flour mill floor litter in Athens, contributing significantly to the cheyletid mite diversity within Greek stored product environments.

Building upon the above taxonomic work, Eliopoulos et al. (2002) undertook a two-year survey of predatory mites in stored products across Greece, sampling from diverse storage facilities including granaries, warehouses, concrete silos, farm stores and flour mills. They collected mites from various stored commodities, including grains, flours, legumes, and dried fruits. The survey documented 14 predatory mite taxa from two orders and six families. *Cheyletus malaccensis* emerged as the most prevalent and dominant species, followed in abundance by *Blattisocius keegani*, along with *Cheyletus eruditus*, *Acaropsis docta*, and *Blattisocius tarsalis*. Grain storage had the greatest predatory mite presence, and the composition of the predatory mite fauna exhibited differences among stored product categories.

Stejskal et al. (2003) examined arthropod infestations within two primary grain storage systems in Central Europe such as horizontal flat stores (HFS) and vertical silo stores (VSS). Their survey, conducted across 147 storage sites in the Czech Republic, documented 25 mite species alongside psocids and beetles. Prominent pest mite species such as *Lepidoglyphus destructor, Tyrophagus putrescentiae* and *Acarus siro* were consistently present in both types of storage facilities. While the total number of mite individuals did not significantly differ between HFS and VSS, the study concluded that both types of storage pose similar risks for mite infestations. Their study highlights the importance of understanding species composition and infestation levels in different grain storage systems to mitigate economic losses and public health risks associated with stored-product pests.

White et al. (2003) carried out two experimental studies to evaluate the susceptibility of Canadian wheat and oilseed cultivars to infestation by stored-product mites. The first experiment examined the multiplication of *Acarus siro* and *Acarus farris* on whole and crushed seeds of wheat, sunflower, flax, soybean, rape, and mustard after 15 weeks of incubation. *A. siro* thrived on wheat, particularly crushed wheat, showing significant multiplication rates. In contrast, *A. farris* struggled on all cultivars. *A. siro* also reproduced on whole sunflower, mustard, and flax, while *A. farris* showed minimal increase only on whole sunflower. The second experiment tested *A. siro*, *A. farris*, *Aeroglyphus robustus*, *Lepidoglyphus destructor*, and *Tyrophagus putrescentiae* on Columbus and Neepawa wheat. *A. siro* and *T. putrescentiae* showed high multiplication on crushed wheat. *L. destructor*, *A. robustus*, and *A. farris* populations remained low. The study concluded that while all tested mites can survive on whole cereals and oilseeds, *A. siro* and *T. putrescentiae* pose a greater risk, especially in damaged cereals. Crushing oilseeds appeared to inhibit mite propagation, likely due to high oil content.

The spatial and temporal patterns of pests in stored grain settings play a pivotal role in shaping effective pest management protocols. Reflecting the importance of such patterns, Athanassiou et al. (2003) conducted a detailed investigation into the spatial distribution and seasonal population dynamics of insects and mites within horizontally stored wheat in southern Greece. The study was conducted in three flat storage units, each holding about 45 tons of wheat, and examined pest distribution based on both the depth and horizontal position within the stored grain. Sampling occurred at 10-day intervals over a ten-month period, using partitioned triers across different zones (central, edges, and corners) and at three depth levels. While temperature showed little variation across depths and zones, moisture levels were notably higher in the upper layers of the bulk. Among the pests identified, *Plodia interpunctella, Rhyzopertha dominica,* and *Oryzaephilus surinamensis* were the dominant insect species, whereas *Acaropsis sollers*, *Tyrophagus putrescentiae*, and *Glycyphagus* *domesticus* were the most prevalent mites. Peak populations occurred in autumn, with the highest densities observed in the corners and top layers of the stored grain. Interestingly, *A. sollers* displayed a more uniform vertical distribution compared to other species.

A wide range of buckwheat storage products, such as whole grains, processed cereals, and milling by-products, were surveyed by Chmielewski (2004) in Polish granaries and storage facilities, revealing the presence of more than twenty mite species. The study identified economically damaging pest mite species, such as *Acarus farris*, *Acarus siro*, *Acarus immobilis*, *Tyrophagus longior*, *Tyrophagus putrescentiae*, *Glycyphagus domesticus* and *Lepidoglyphus destructor*. Additionally, predatory species, namely, *Cheyletus eruditus*, *Acaropsis sollers*, *Melichares tarsalis*, and *Bdella* species, were observed, highlighting their natural regulatory role within these ecosystems.

Stejskal et al. (2006) carried out a survey in northern Namibia to document stored-product pests and associated predatory species across different crop commodities and storage types. While the survey identified numerous insect pests, no stored product mites (Acari) were found. However, the potent predatory mite *Blattisocius tarsalis* was recorded as a predator of insect pests, indicating potential for predatory mite-based biological control in Namibian grain stores.

Thind and Ford (2006) evaluated the efficacy of two predatory acarine species viz., *Blattisocius tarsalis* and *Cheyletus eruditus* to suppress persistent populations of *Acarus siro* in post-harvest storage systems. *C. eruditus* devoured motile stages of *A. siro*, achieving a maximum predation rate of 82%, whereas *B. tarsalis* primarily preyed on the eggs, with a minimum predation rate of 99%. The presence of prey refuges and grain debris hindered the predatory performance of *C. eruditus* but did not affect *B. tarsalis*. In longer-term exposures, *B. tarsalis* controlled the *A. siro* population, achieving a maximum 80% reduction, and simultaneous application of the two predatory mite species showed no additive effect on pest regulation. The results demonstrated the potential of predatory mites for controlling stored product pest mite populations, particularly their stage-specific predation strategies.

survey of stored grain residues and composite flour samples collected from warehouses and milling facilities throughout Cairo, Egypt. The survey recorded twenty-one species of mite, comprising twelve pest mite species, seven predatory mite species, and two parasitic species. The pest mites *Dermatophagoides farinae*, *Tyrophagous putrescentiae*, and the predatory mite *Cheyletus malaccensis* were frequently encountered in all collected samples at all inspected locations. *Pyemotes herfsi*, *Acrus siro* and *Acarophenax tribolii* were frequently abundant. Mite species diversity and infestation intensity varied across the sampling sites, with mixed flour from Qaliobia Governorate, Egypt exhibiting the highest species richness. They also noted that the overall mite species richness was higher in mixed flour than in grain residue samples. They meticulously investigated various elements shaping population trends, including species dominance, occurrence rates, population variability over time, and the influence of temperature and humidity levels.

Hubert et al. (2006) analysed and catalogued mite communities in stored grain facilities, comparing grain mass and grain residues as different habitats. They surveyed 78 grain stores and identified 30 mite species in residues and 23 in grain mass, with significantly higher mite abundance and diversity in residues. Important species such as *Tydeus interruptus, Tyrophagus longior*, *Cheyletus eruditus* and *Acarus farris* and were primarily associated with residues, while *Cheyletus malaccensis*, *Acarus siro, Lepidoglyphus destructor, Tarsonemus granarius*, and *Tyrophagus putrescentiae* were found in both habitats. Despite the higher mite presence in residues, the study revealed that mite abundance and species richness showed no significant association between the two habitats, indicating minimal ecological connectivity.

Gamila et al. (2007) investigated the influence of temperature on the population growth of three key mite species commonly associated with stored products, namely *Tyrophagus putrescentiae, Acarus siro* and *Auleroglyphus ovatus*. The study examined mite population growth rates across a temperature range of 5 to 35°C at 85% relative humidity. The findings revealed that mite populations expanded more rapidly at moderate temperatures, with optimal growth observed at 25°C. The observations from the study revealed lower and upper temperature thresholds for development. When simulating population growth under actual storage conditions, it was observed that these mite species exhibited population increases during only 3.5 months of the standard 9-month grain storage period in Central Europe.

In a comprehensive field-based assessment of predatory mite populations in Czech grain storage facilities, Lukaš et al. (2007) evaluated the natural performance of four *Cheyletus* species commonly found in Central European storage environments. Through an extensive survey of 147 grain stores, encompassing over one million pest mites and approximately 40,000 predatory mites, the study found that *Cheyletus eruditus* dominated the predatory mite community, accounting for 79% of collected individuals. Other species, including *C. aversor*, *C. trouessarti*, and *C. malaccensis*, were present in smaller proportions. While most *Cheyletus* species showed a strong positive correlation between predator and prey mite densities, *C. malaccensis* did not follow this density-dependent pattern.

Over a six-year period, Palyvos et al. (2008) carried out a extensive survey of acarine species linked to stored agricultural products in Greece. They examined 1,073 samples from various storage facilities across 34 Greek counties and identified 65 mite taxa across 15 families. Their study revealed six mite species that were new reports to Greece, and five species were recorded for the first time occurring on stored products in Greece. The highest percentage of infestation was observed in samples from agricultural cooperative union stores, and residue materials exhibited the highest levels of infestation. Common pest mite species such as *Acarus siro, Tyrophagus putrescentiae* and *Lepidoglyphus destructor* were widely distributed, and *Cheyletus malaccensis* was the most prevalent predatory mite.

In a comparative study involving 79 Czech grain storage sites, Hubert et al. (2009) found that barley was notably more prone to mite infestations than wheat. Compared to wheat, barley samples consistently showed higher mite abundance, greater occurrence frequency, and increased species diversity. The mean acarine abundance was 506 individuals per sample in barley versus 55 in wheat, with 10% of barley samples exceeding the allergen risk threshold. The study recorded 25 mite species, among which *Acarus siro, Tydeus interruptus, Tarsonemus granarius, Tyrophagus putrescentiae* and *Lepidoglyphus destructor* were found to be the most frequent. Principal components analysis revealed a more substantial association of *Tyrophagus putrescentiae, T. interruptus, L. destructor*, and *Cheyletus eruditus* with barley, likely due to the higher proportion of crushed grain particles providing favourable nutrient sources.

The study by Gill et al. (2011) investigated the occurrence of acarine contamination in dry dog food across different container types during a 90-day storage period. Different species of mites belonging to genus *Dermatophagoides* and the genus *Tyrophagus* were identified in the food samples, with paper bags exhibiting the highest levels of contamination. While sealable plastic containers were effective in preventing mite contamination, paper and plastic bags did not provide sufficient protection. Although mite allergens were detected in the food, the study concluded that the levels were significantly lower compared to those found in household dust, suggesting that stored pet food is a relatively minor source of mite allergen exposure.

Athanassiou et al. (2011) conducted a study on the spatial distribution patterns of mites and insects in stored wheat housed in a steel silo located in central Greece over a seven-month time period. Using grain trier samples and probe traps, they identified *Blattisocius tarsalis* and *Lepidoglyphus destructor* as the most abundant mite species. The phytophagous mite *L. destructor* exhibited greater abundance in the peripheral zones of the grain mass, whereas the predatory mite *B. tarsalis* exhibited a dispersed distribution. Notably, *B. tarsalis* was more spatially associated with insect populations than with *L. destructor*, indicating its predatory role.

Collins (2012) made a comprehensive review of factors influencing pest mite growth in stored grains, identifying humidity, grain moisture content, natural predator presence, and commodity type as key determinants of population dynamics. The review highlighted critical research gaps, including the impacts of climatic change, light exposure, species interactions, density-dependent responses, mycotoxin contamination, and actionable thresholds. Collins emphasized that resolving these gaps is essential for refining predictive models and developing alternative control strategies.

Britto et al. (2012) recorded species belonging to the predatory mite genus *Blattisocius*, inhabiting commercial dog food in Brazil. They identified and described a new species, namely *Blattisocius everti*, and redescribed its closely related species, *Blattisocius keegani*. In addition to the key findings, they also provided a dichotomous key for identifying world species within the genus *Blattisocius*.

Ardeshir (2017) carried out extensive surveys to explore the cheyletid mite fauna in stored grains in Iran, collecting samples over 15 years (1996-2010) from various storage facilities, including barns, silos, rice and flour mills, across 12 provinces. The survey recorded eight genera and thirteen species of cheyletid mites viz., *Cheletomorpha lepidopterorum, Culifella variegata, Acaropsellina sollers*, *Cheyletus bidentatus*, *Cheyletus carnifex*, *Cheyletus eruditus*, *Cheyletus malaccensis*, *Cheyletus malayensis*, *Cheyletus trouessarti*, *Lepidocheyla gracilis*, *Nodele calamondin*, *Neoeucheyla iranica*, and *Zachvatkiniola reticulata*. *Cheyletus bidentatus* was found to be a new record for the mite fauna of Iran. *Cheyletus malaccensis* and *Acaropsellina sollers* were identified as the most widely distributed mite species. The study noted that predatory mites were most prevalent in wheat and associated dust, accounting for 25% of the total occurrences. The key findings provided a comprehensive overview of cheyletid mite diversity in stored grains in Iran.

Carvalho et al. (2018) summarized the dual role of stored product mites in the food industry, particularly in Brazil, highlighting their impact as both a problem and a beneficial agent. On one hand, mite infestations can cause significant economic losses and reduce the quality of stored products, particularly in cheeses requiring long ripening periods. On the other hand, certain cheese varieties, such as Mimolette and Milbenkäse, rely on mites to develop their distinctive flavours, showcasing their role as coadjutants in food technology. The study emphasized that effective control of mite infestations is best achieved through good manufacturing practices rather than synthetic or botanical acaricides. The findings highlighted a gap in knowledge regarding the health risks associated with consuming mite-containing cheeses, despite their growing popularity in Brazil. Their study outlined the taxonomic identity of mites found in these cheeses, potential health concerns, and the technological and regulatory challenges involved in their production. This comprehensive analysis aims to support the development of mite-containing cheese production in Brazil while addressing safety and quality concerns.

The exploration of predatory mites belonging to the family Cheyletidae holds significant importance, as they are potent biological control agents against pest species. Supporting this, Salarzehi et al. (2019) reported the discovery of a previously undescribed cheyletid mite species, *Cheletonella iraniensis* which was recovered from stored materials, including rice flakes, barn, and barley, in Guilan Province, Northern Iran. The study also provided a key to the world species belonging to the genus *Cheletonella*. The new species was assigned to the tribe Cheyletini and genus *Cheletonella* based on the characteristically large propodosomal shield.

In a two-year study, Mohamed et al. (2019) surveyed various mite species, including predators, fungivores, and parasites associated with insects in stored maize grains from 14 untreated stores in Giza Governorate, Egypt. The survey recorded 21 mite species belonging to four suborders: Astigmata, Prostigmata, Mesostigmata, and Cryptostigmata. Important predatory mites identified included *Cheyletus malaccensis*, *C. eruditus*, *Proctolaelaps pygmaeus*, *Blattisocius tarsalis*, *Lasioseius aegypticus*, and *Androlaelaps casalis*, highlighting their potential as biological control agents for stored maize insect and acarine pests. The study also documented six insect species from the order Coleoptera.

Blattisocius is a small but economically important predatory mite genus, with 17 described species worldwide. A recently described species, *Blattisocius flagellatus*, was identified by Hassan et al. (2020) from samples of stored maize grains collected in Giza, Egypt. This species is distinguished by 33 pairs of long, flagellate setae on its dorsal shield, a ventrianal shield bearing three pairs of pre-anal setae, and chelicera featuring a fixed digit shorter than the movable digit. Their study also provided an identification key for the eight *Blattisocius* species recorded in Egypt.

Gallego et al. (2020) assessed the predatory potential of two predatory mite species, *Blattisocius tarsalis* and *Macrocheles robustulus* as promising biological control agents against *Phthorimaea operculella*, commonly known as the potato tuber moth, infesting stored potatoes. Under laboratory conditions, *B. tarsalis* effectively preyed upon the eggs of *P. operculella*, exhibiting a type II functional response, whereas *M. robustulus* failed to exhibit any predatory activity. The study demonstrates the predatory potential of *Blattisocius tarsalis* as a biological control agent for *P. operculella* in stored potatoes.

Ebrahimi and Noei (2022) compiled a comprehensive summary of Iranian stored product mite fauna, drawing from published literature. A total of 144 mite species were identified in the study, spanning 90 genera, 45 families, 27 superfamilies, three suborders, three orders, and two superorders. Notably, the families Acaridae and Cheyletidae exhibited the highest species richness, followed by Laelapidae. Their work provides a valuable overview of the extensive diversity and distribution of stored product mites in Iran.

Species within the family Laelapidae are often recognized as effective predators and commonly found in stored edible commodities. Zhang et al. (2022) determined the predation ability of *Stratiolaelaps scimitus* on *Tyrophagus putrescentiae*, a major pest of edible fungi. The study aimed to determine the prey preference and predation rates of *S. scimitus* in a laboratory setting. Results indicated that both female and male adult *S. scimitus* preferentially preyed on adult *T. putrescentiae* over larvae. Female *S. scimitus* exhibited higher daily consumption rates than males, with both sexes showing peak consumption and predation within the first hour, followed by a gradual decline. The research provided a theoretical foundation for the mass rearing of *S. scimitus* and its application in the biological control of *T. putrescentiae* on edible fungi.

Danso et al. (2023) investigated the potential of the predatory mites *Cheyletus eruditus* and *Cheyletus* as biological control agents against the stored-product pest *Liposcelis decolor* (psocids) under simulated storage conditions. Their study examined the effects of varying predator-prey ratios, temperatures, and relative humidity on psocid population suppression and predatory mite reproduction. Results indicated that both mite species effectively preyed on *L. decolor*, leading to significant psocid population reductions and substantial increases in mite progeny. They also highlighted that *C. eruditus* is commercially utilized for pest management in stored grains in the Czech Republic, under the commercial name Cheyletin, demonstrating its practical application in food storage systems.

Arco et al. (2024) explored the biocontrol potential of three predatory mite species viz. *Amblyseius swirskii, Blattisocius tarsalis* and *Cheyletus malaccensis* against insect pests commonly found in stored cereals. They found that *B. tarsalis* and *C. malaccensis* displayed a wide range of feeding preferences, effectively preying on various stored product insects, while *A. swirskii* was ineffective. *C. malaccensis* and *B. tarsalis*, whether used separately or together, were highly effective in lowering the numbers of *Sitotroga cerealella* and *Oryzaephilus surinamensis*. The study suggests that these predatory mite species offer a promising alternative to synthetic insecticides for pest management in stored cereals, demonstrating their potential for periodic releases to maintain pest populations under control.

2.1.2 Research from India

Girish et al. (1971) reported the occurrence of a cheyletid mite, *Acaropsis docta*, in stored grains in Hapur, Uttar Pradesh, observing its association with key insect pests viz., *Trogoderma granarium* and *Rhizopertha dominica*. Their findings emphasized the role of *A. docta* as an effective predatory mite species, suggesting its potential as a biological control agent against these destructive pest insects. Complementing these findings, Somchoudhury and Mukherjee (1971) explored the same species in stored wheat samples from West Bengal. They reported seasonal variations in its population, suggesting that environmental conditions within storage facilities significantly influence its abundance.

The identification and description of new predatory mite species from India hold considerable scientific importance. Mathur and Mathur (1981) described *Hemicheyletia hissariensis*, a new cheyletid mite species, discovered during a survey of stored grain mites in Hissar district, Haryana. The detailed descriptions and illustrations were based on a single female specimen extracted from wheat straw debris. This new species is closely related to *Hemicheyletia granula*, but it can be distinguished by several key morphological differences, including fan-shaped dorsal body setae, a dorsal seta on the palp femur similar to dorsal body setae, concentric striae encircling the eyes, and a distinct number of teeth on the palp claw.

Mathur and Minocha (1989) investigated the cannibalistic behavior of *Acaropsis sollers* in relation to host stage density. Their study revealed that both adult and developing stages of the mite exhibited cannibalism even in the presence of natural food sources. *A. sollers* preferentially consumed eggs and early developmental stages of its own species, while avoiding healthy adults. The key findings from the study revealed that cannibalism in *A. sollers* may not solely be a survival mechanism under adverse conditions or a means of population control, but rather a strategy to enhance feeding capacity. This enhanced feeding capacity significantly increases the potential of *A. sollers* as a biological control agent against the common stored product pest insect *Trogoderma granarium*.

Stored, cured, and dried fish products are distinct in nature from conventional post-harvest agricultural commodities. Despite their high salt content, cured and dried fish are often susceptible to mite infestations. In India, storage practices for these products differ from those of traditional crops, characterized by shorter storage durations and distinct environmental conditions. A year-long exploratory study in Kerala by Cicillikutty and John (1981) documented *Suidasia medanensis* infesting a total of 38 species, encompassing cured fish, prawns, and molluscs. This reveals the remarkable adaptability of *S. medanensis* to such challenging environments.

Mathur and Mathur (1983) documented 13 mite species from eight families associated with various stored products and grains in Haryana. This survey included granivorous, predatory, parasitic, and scavenger species. Notably, 5 species represented new records for India, and all 13 species were reported for the first time in Haryana. The study encompassed a wide range of stored products, including wheat, wheat straw debris, rice and rice bran, barley, oats, pearl millet, Bengal gram, green gram, lentil, cowpea, dried peas, and mustard. Cheyletid mites were found to be the dominant group within the reported mite fauna.

Nangia and Channabasavanna (1989) conducted a comprehensive survey of stored product mites in Karnataka. Detailed inspection of 67 distinct stored product types documented the incidence of 53 mite species, belonging to 16 families and 3 orders. Notably, 12 species represented new records for India, and 43 species were reported for the first time from Karnataka. The study revealed a high incidence of mite presence, with 88.7% of the 2575 stored product samples testing positive. Astigmatid mites dominated the acarine fauna, comprising 65.6% of the identified species, while Prostigmata and Mesostigmata mites accounted for 20.5% and 13.9%, respectively. Among whole grains, wheat exhibited the highest susceptibility to mite infestations.

Putatunda et al. (1999) documented 24 mite species associated with stored food products in Haryana. The survey reported different species of mites from three orders, namely Mesostigmata, Astigmata, and Prostigmata. *Dermatophagoides farinae* and *Aleuroglyphus ovatus* were found to be the most prevalent pest mite species infesting stored food commodities, while *Cheyletus malaccensis* and *Acaropsis docta* were found to be the most abundant predatory mites.

Gupta and Gupta (1999) compiled a comprehensive review of the reported acarine fauna inhabiting various stored products in India, reporting 88 mite species spread across 20 families and 50 genera. This summarized data served as a valuable resource for researchers and practitioners, providing a consolidated overview of mite diversity and distribution in Indian stored commodities.

An investigation by Putatunda (2004) on mites infesting stored food commodities in Himachal Pradesh, India, identified *Leiodinychus parasiticus* as the most dominant species in terms of population density. Among stored product pests, *Acarus siro* infested the widest variety of commodities (seven types), followed by *Tyrophagus longior* (four types) and *Aleuroglyphus ovatus* (three types). Other species, including *Caloglyphus berlesei*, *Tarsonemus confusus*, *Pygmephorus nilanjana*, *Thyreophagus entomophagus*, *Glycyphagus geniculatus* and *Austroglycyphagus geniculatus* were also identified, but with lower infestation rates. Notably, *Cheyletus malaccensis* was identified as the most dominant predatory mite, actively present in nine different stored products.

While some studies on stored-product mites have been conducted across various regions of India, West Bengal, particularly the Kolkata, remained notably understudied. Recognizing this knowledge gap, Gupta and Chatterjee (2004) conducted a three-year study to assess mite infestations in stored wheat and rice in Kolkata, West Bengal, revealing 36 mite species from 13 families and 24 genera across three orders. Notably, nine species were reported for the first time infesting stored grains in West Bengal. Their study identified various mite groups based on their feeding habits, including grain feeders, fungivorous, predatory, and species with diverse food habits. The predatory mites, including *Cheyletus eruditus*, *Cheyletus malaccensis*, *Blattisocius tarsalis*, and *Cunaxa setirostris*, were commonly found in both wheat and rice samples.

Sandhu et al. (2005) inspected stored grains and processed products in Hisar, Haryana, from 1999 to 2002, identifying seven mesostigmatid mite species. These included *Phytoseius* species, *Androlaelaps theseus*, *Leiodinychus parasiticus*, *Haemolaelaps ovalis*, *Hypoaspis aculeifer*, *Hypoaspis sardoa* and *Ornithonyssus nitedulae*. Notably, six of these species, excluding *Phytoseius* sp., were reported for the first time from Haryana, while four constituted new records for India in the context of stored product habitats. *Leiodinychus parasiticus* was found to be the most abundant species.

Exploratory research in India regarding the survey and identification of new predatory mite species associated with stored products trails behind international efforts. In this context, any contributions from India to this field are highly valued. Anithalatha et al. (2010) conducted a faunistic survey on various stored commodities and identified and described a novel predatory mite, *Cheyletus arecae*, from Kerala, India. *Cheyletus arecae* shares similarities with *C. baloghi* and *C. palmae* in dorsal shield structure, chaetotaxy, setae, and palp claw teeth numbers, but exhibits distinct differentiating characteristics from other known species within the genus *Cheyletus*.

Chakraborty and Gupta (2016) undertook an exploratory study of mites occurring in household stored products in South Bengal, documenting 29 species from 19 genera and 10 families. This study identified 17 species as damage-causing pest mites and 12 as predatory mites. Notably, 13 species were reported for the first time on stored products in South Bengal, expanding the known habitats of these mites. The study provided information on the nature of damage, habitats, distribution, and economic importance of the identified mite species, as well as 13 new habitat records.

Cured and dried marine fishes, an economically important stored commodity, serve as an unusual habitat for acarine fauna. James et al. (2017) conducted an exploratory investigation and documented 20 mite species inhabiting various stored marine dry fishes in Kerala. The study identified ten acarine species belonging to seven genera, five families, and three orders. *Lepidoglyphus konoi* was the most abundant species, particularly on dried prawns, solefish, and orangefin ponyfish. Orangefin ponyfish and Indian anchovy exhibited the highest mite diversity. *L. konoi*, *L. zacheri*, *L. destructor*, *Tyrophagus putrescentiae*, and *T. longior* were found to be potentially damaging mite species, while *Cheyletus malaccensis*, *C. fortis*, *C. eruditus*, and *Lasioseius* sp. were predatory. Twelve out of the 20 fish samples exhibited mite infestations, with dried prawns showing the highest infestation frequency.

Gill and Dehar (2018) conducted a year-long survey to investigate acarine species infesting stored food commodities in the Patiala district of Punjab, India. Examining 60 samples across summer, rainy, and winter seasons, they found a 60% mite infestation rate, identifying 14 mite taxa from 7 families across 3 orders, with Astigmata mites being dominant. The rainy season exhibited the highest mite abundance (51.07%), followed by summer (31.68%) and winter (17.25%), correlating with mites' sensitivity to temperature and humidity, with optimal conditions around 25°C and 60-80% relative humidity. *Glycyphagus destructor*, *Acarus siro*, and *Tyrophagus putrescentiae* were the most prevalent species, with Acaridae mites being the most common family. The study underscores the significance of mites in stored food products and suggests the necessity for further investigations into their ecology and control.

James et al. (2018) documented the occurrence of mites in stored products across four districts of the Malabar region in Kerala, identifying 33 species from 14 genera, 12 families, and 3 orders (Trombidiformes, Mesostigmata, and Sarcoptiformes). The Cheyletidae family was found to be the most dominant, with *Cheyletus malaccensis* being the most abundant species. Families Stigmaeidae and Cunaxidae were also prevalent. Pepper exhibited the highest mite species diversity, followed by boiled and raw rice. Notably, the study reported three potentially undescribed species from the genera *Lasioseius*, *Stigmaeus*, and *Tydeus*. However, the precise identification of all collected specimens to the species level was not yet completed in this study.

Martin et al. (2018) conducted a six-month survey of acarine fauna in stored products across five districts of North Kerala, collecting predatory mites from cereals, pulses, oil seeds, spices, and dried vegetables. Identification revealed 20 predatory mite species from 12 genera, 5 families, and 2 orders (Trombidiformes and Mesostigmata). Mesostigmatid mites showed the highest diversity, with 11 species from 9 genera and 2 families. Dried ginger exhibited the highest diversity of predatory mites, and *Cheyletus malaccensis* was the most abundant species. It is important to note that out of the 20 predatory species collected. In this study, five of the 20 collected species were not confirmed to species level.

Expanding the documented list of predatory mite fauna inhabiting stored products, particularly in Kerala, Martin and James (2023) described and illustrated *Acaropsella strioreticulata*, a novel cheyletid mite species, discovered in wheat semolina from Kerala, India. This study also marks the first recorded occurrence of the genus *Acaropsella* in India. The species description is based on the morphological characteristics of adult females. In the same year, Martin and James (2024) also discovered and described a new smaridid predatory mite species, *Fessonia indica*, collected from rice in Kerala. This discovery expands the known *Fessonia* species in India to three. The species description is based on the morphology of post-larval instars, and the study provides a key for the identification of Indian *Fessonia* species.

2.2. Part II- Developmental studies

The stored product ecosystem harbours a diverse range of mite species, including both pests and predatory forms. Numerous studies worldwide have explored their developmental biology, ecology, and interactions; however, a comprehensive review of all such studies would be unnecessarily broad and could detract from the specific focus of this research. Among predatory mites, the family Cheyletidae stands out due to its recognized potential in regulating stored product pest populations. Notably, *Cheyletus malaccensis* has emerged as a key species of interest because of its wide distribution and strong predatory capacity. Therefore, this literature review focuses primarily on developmental and biological control studies related to *Cheyletus malaccensis* and its close relatives.

2.2.1 Research from Abroad

The exploration of predatory mites for stored product pest control has spanned more than a century and remains a focus of ongoing scientific investigation. Among the early observations of predatory mites in stored product habitats, *Cheyletus seminivorus* Packard received notable attention for its association with pest-infested grains. This species was initially described by Packard in 1869, later studied in detail by Ewing (1912), who clarified misconceptions about its feeding habits. Although originally assumed to be seed-feeding due to its presence in stored seeds, such as cabbage seed, it was later confirmed to be entirely carnivorous. Ewing's laboratory investigations, prompted by the discovery of *C. seminivorus* in wheat samples infested with Tyroglyphid mites, revealed its predatory nature and potential ecological role in suppressing pest mite populations. Despite being found in small numbers initially, the mite demonstrated adaptability and predation efficiency, suggesting its value in naturally managing pest outbreaks. Ewing emphasized that such mites should not be mistaken as pests but rather recognized as beneficial allies within stored product ecosystems.

Gause et al. (1936) conducted detailed experiments to understand predator-prey dynamics using *Cheyletus* species as predators. Their findings emphasized how environmental conditions and prey accessibility significantly influence the predatory efficiency of *Cheyletus* mites. Predation was most effective on firmer substrates like millet, where prey was easily accessed and quickly eliminated. In contrast, in less structured media such as flour, the predatory impact was reduced, sometimes resulting in delayed prey suppression or partial predator mortality. The study also observed that occasional immigration events could trigger population oscillations, suggesting that *Cheyletus* mites play a dynamic role in stored product ecosystems under varying environmental conditions.

Solomon (1967) explored predator-prey interactions between *Cheyletus* spp. and *Acarus* spp. within stored wheat, focusing on the crucial role of abiotic factors such as temperature and humidity. The findings revealed that the interaction dynamics were heavily limited by environmental conditions, with specific temperature-humidity combinations proving unsuitable for either the prey, the predator or both. However, within the limited range of tolerable conditions, certain environmental profiles favored effective predation and potential prey suppression, while others reduced the predator's efficiency. Additionally, *Cheyletus* mites were found to be relatively resilient during declining prey populations, displaying a capacity to endure extended periods without food. This survival was often facilitated by behaviors such as cannibalism, which delayed population collapse, but also led to a relaxation-type interaction as characterized by initial prey depletion followed by predator decline.

In a study by Zaher and Soliman (1971), the developmental durations for the various life stages of *C. malaccensis* were documented. This investigation deployed *Caloglyphus* sp. as a prey source. Their findings indicated that the average incubation period for *C. malaccensis* eggs was 6.6 days when maintained at 19.5°C. Furthermore, the combined duration of the immature stages (larval, protonymphal, and deutonymphal stages) exhibited distinct differences between sexes as these immature phases collectively spanned an average of 19.4 days for female mites, whereas male mites completed these stages in approximately 16.5 days.

Žďárková and Pulpán (1973) examined the cold storage potential of the predatory mite *Cheyletus eruditus* as a means of supporting biological control programs in stored product environments. Their study demonstrated that *C. eruditus* populations were capable of withstanding prolonged exposure to low temperatures ranging from -1.7°C to +2.0°C, combined with high relative humidity levels (80-90%), for periods extending up to 6.5 months. Importantly, the mites retained reproductive viability after being returned to more favorable environmental conditions. This ability to survive and remain functionally active after long-term cold storage suggests the feasibility of stockpiling naturally collected populations of *C. eruditus* for strategic deployment in integrated pest management systems targeting storage mite infestations.

Summers and Witt (1973) carried out an early investigation into the reproductive behavior of *Cheyletus malaccensis*, focusing on oviposition patterns and mating dynamics under laboratory conditions. Their observations revealed that parthenogenetic females typically initiated egg-laying approximately around the third day after the final moult, with the reproductive period lasting between 40 and 56 days. Among 19 unmated females, the average number of eggs laid was 294.2, with the highest recorded at 406. Mating was most successful when males were introduced shortly after the final moult but before the onset of oviposition. No successful matings were observed when males were added during the initial 30 days of the egg-laying phase.

Regarding nesting and longevity, the study noted that females deposited their eggs in self-constructed nests. Isolated individuals monitored under minimal disturbance lived for an average of 64.7 days, with more than 50 days spent in nesting activity. The number of nests constructed varied, with most females producing one or two, while a few built three. It was also observed that a few females, when continuously confined with their own sons, accepted mating toward the end of their oviposition period. These detailed observations contribute important knowledge on the reproductive traits and behavioural tendencies of *C. malaccensis*, which are relevant for improving its handling in laboratory cultures.

Cheyletus eruditus is also recognized as an important predator of storage mites, and its feeding ecology was analysed in detail in an earlier study by Berreen (1976). This study challenged earlier assumptions by demonstrating that both adult and protonymph stages of *C. eruditus* are capable of preying on all developmental stages of the pest mite, *Acarus siro*. These results challenged the assertions made by Rodionov and Furman (1940), who proposed that juvenile *Cheyletus* targeted only the immature stages of grain mites, and that adult individuals fed on immature prey only when adult prey was unavailable.

Regarding predation dynamics, Berreen further identified prey age preferences across predator stages, with adults predominantly targeting older prey and protonymphs preferring younger stages. Statistical analysis showed that prey killed per instar deviated significantly from expected proportions based on initial prey availability. However, no significant difference was found in the overall predation rates between adults and protonymphs. The combined predation rate of *C. eruditus* was 5.03 prey per predator per day, with 95% confidence limits of 4.13-5.93. These findings highlight the broad predatory capacity of *C. eruditus* across multiple prey stages, emphasizing its potential role in managing mite populations in stored product environments.

Cunnington (1976), in a study conducted in the United Kingdom, investigated the developmental limits of important pest species of stored food products such as *Glycyphagus destructor, Acarus siro* and *Tyrophagus putrescentiae*. His findings emphasized that *A. siro* failed to develop below 60% relative humidity, regardless of temperature, highlighting the critical role of humidity in the developmental biology of mites. He observed that the most rapid development occurred at around 25°C and 90% RH, with the potential for over thirty generations per year under such conditions. While mites exhibited the highest total fecundity under cooler and more humid conditions (around 15°C and >80% RH), their daily oviposition rate was faster at temperatures that supported quicker development, such as 25°C. Comparable physiological responses were recorded for *T. putrescentiae* and *G. destructor*, though species-specific thresholds varied. These results highlighted the importance of environmental conditions in determining mite fitness and underscore the need to consider these parameters when evaluating the efficacy of predatory mites such as *Cheyletus* spp. under storage conditions.

Rizk et al. (1981) provided detailed observations on the biological traits of *Acaropsis sollers* when reared on various prey types. Their study involved feeding the predator with early developmental stages such as eggs and freshly emerged larvae of stored product pests like *Tribolium confusum* and *Lasioderma serricorne*, as well as adult specimens of the house dust mite *Dermatophagoides farinae*. A notable outcome of this research was the observation that females of *A. sollers* exhibited longer developmental periods and extended adult longevity in comparison to males.

The complex biological responses of *C. malaccensis* to variations in prey stage and temperature were explored in a study by Yousef et al. (1982). This research involved rearing *C. malaccensis* on different developmental stages of *T. putrescentiae*, specifically eggs, larvae, nymphs, and adults. A key finding was that the consumption of *T. putrescentiae* eggs and larvae consistently resulted in shorter developmental periods for the predator's immature stages when compared to diets of nymphs or adults. Their study further indicated an inverse relationship between the predator's nutritional requirements and the size of the prey; as the prey matured and increased in size, the number of individuals consumed by the predator correspondingly decreased. During its immature phases, *C. malaccensis* exhibited a clear preference for prey larvae, followed by eggs, then nymphs, and lastly, adults. Interestingly, despite being consumed in smaller quantities, house fly eggs and larvae remarkably stimulated higher fecundity in the predator. Conversely, female *C. malaccensis* produced the fewest eggs when fed immature *T. putrescentiae*. The influence of temperature was also significant, as an increase in temperature led to a reduction in the total amount of prey consumed, yet simultaneously elevated the mean daily consumption rate. Moreover, the fecundity of adult female *C. malaccensis* demonstrated a positive correlation with rising temperatures.

Among the various predatory mites explored in previous studies for the biological control of stored product pests, *C. eruditus* has been highlighted for its promising predatory capacity and suitability for mass-rearing under controlled conditions. Žďárková (1986) developed a practical and effective method for culturing *C. eruditus* using lettuce seeds as a substrate under controlled conditions (25°C and 75% relative humidity). When introduced at predator-prey ratios of 1:100–1:200, each culture unit yielded over 2,000 mites within a month. The paper bags used for rearing served as both breeding and transport containers, making the system highly adaptable for field application.

Regarding its application and storage, lettuce seed cultures allowed predator populations to multiply while suppressing *A. siro* populations by several hundred-fold. Despite the predator's ability to eliminate prey populations, cannibalism was observed when prey became scarce, emphasizing the importance of timing in culture termination. Additionally, mites could be stored at low temperatures (0 ± 1°C) for up to three months without significant loss. This method was implemented operationally in Czechoslovakia for warehouse-level pest management, offering both preventive and curative control. The study highlights the feasibility of deploying *C. eruditus* in commercial biocontrol programs, especially where chemical residues limit repeated pesticide use.

A few studies have investigated the developmental differences between mated and unmated individuals in *Cheyletus malaccensis*, indicating the influence of mating on reproductive performance and predatory potential. Among these, Saleh et al. (1986) conducted a comprehensive assessment of the life history traits and predatory efficacy of *C. malaccensis* under controlled conditions (28 ± 1 °C and 75 ± 5% RH). Their findings showed that mating significantly enhanced female fecundity, with copulated females laying an average of 50.6 ± 1.2 eggs, nearly double the 25.7 ± 0.2 eggs recorded for virgins. Mating also affected reproductive timing by shortening the pre-oviposition period and extending both the oviposition (10.1 ± 0.3 days) and post-oviposition phases (4.9 ± 0.3 days). Additionally, observations on longevity revealed that females consistently outlived males, regardless of mating status as copulated females lived approximately 17.6 ± 0.3 days, compared to 9.1 ± 0.3 days for copulated males. Notably, sexually produced females showed the highest predation efficiency, consuming an average of 237.7 ± 0.1 *Aleuroglyphus ovatus* adults over their lifetime, which was nearly six times the rate observed in asexually produced males (34.1 ± 0.3).

Zhang et al. (1997) conducted an in-depth study on the developmental biology and predatory capacity of *Cheyletus malaccensis* under controlled temperature conditions between 18°C and 26°C. The developmental cycle of *Cheyletus malaccensis* consisted of five clearly defined stages. viz., egg, larva, protonymph, deutonymph, and adult, with the entire cycle taking approximately 48 to 50 days to complete. Individuals exhibited a daily predation rate of around 10 to 12 prey, amounting to nearly 500 prey over their lifetime. Notably, as the population density of *C. malaccensis* increased, the individual predation rate declined, suggesting density-dependent effects on feeding behavior. Furthermore, the reproductive performance, particularly the fecundity was found to correlate positively with prey availability.

Žďárková and Horák (1999) explored the developmental responses of *Cheyletus eruditus* to lower thermal conditions, assessing its performance at 12°C, 14°C, and 25°C under 75% relative humidity. Their findings demonstrated that 12°C represented the lower developmental threshold for this species, with the complete life cycle extending to as long as 164 days. In contrast, under the same conditions, the prey mite *Acarus siro* completed its development in just 47 days. This pronounced discrepancy in development rates suggested that *C. eruditus* may be ineffective for reactive pest suppression in cool storage environments. Instead, the authors proposed that its use should be focused on preventive control strategies, particularly in storage facilities during empty phases when pest populations are yet to establish.

In an applied context, Žďárková and Feit (1999) evaluated the potential of *Cheyletus eruditus* to suppress mite infestations in oilseed storage environments. Their research showed that when predator-to-prey ratios ranged between 1:20 and 1:50, and initial mite infestations remained below 500 individuals per kilogram, *C. eruditus* was capable of significantly suppressing pest populations. Furthermore, their findings underscored the success of preventive biological control strategies, particularly when the predators were introduced in emptied and cleaned storage spaces. Releasing approximately 2000 individuals across a 100 m² area yielded promising results, suggesting the practicality of this predator in biological control programmes.

Addressing the complexities of pest management in stored grain ecosystems, Pekár and Hubert (2008) conducted a crucial study on the performance of *C. malaccensis* as a biological control agent against *A. siro*. Their investigation specifically explored how temperature and initial prey density influence this predator-prey system under laboratory conditions, employing ratio-response models to quantify control efficiency across different temperatures. The research revealed that achieving a 90% reduction in *A. siro* populations required varying numbers of *C. malaccensis*: specifically, nine individuals at 15°C, seven at 20°C, and three at 25°C, when targeting 100 *A. siro* individuals in 1 kg of grain.

Concerning population dynamics, their study showed that the intrinsic rate of increase in *A. siro* rose with temperature, peaking at a density of 100 individuals, indicating positive interactions. In contrast, *C. malaccensis* also exhibited higher rates at increased temperatures, but these declined with rising predator density, likely due to interference competition. A critical finding was the shift in population dynamics, where the rate of increase in *A. siro* exceeded that of *C. malaccensis* at 15°C, but at higher temperatures, the predator's growth rate became dominant. The research also identified the lower developmental thresholds for *A. siro* at 10°C and for *C. malaccensis* at 13.6°C.

Cebolla et al. (2009) undertook a study to determine the prey range of *C. malaccensis* and assess its effectiveness in controlling seven common stored-product pests. Their laboratory experiments involved exposing *C. malaccensis* to various prey species, including five mite species (*Aleuroglyphus ovatus*, *A. siro*, *Lepidoglyphus destructor*, *Caloglyphus redickorzevi*, and *T. putrescentiae*) and two insect pest egg species (*Tribolium castaneum* and *Ephestia kuehniella*). These trials were conducted in vials containing wheat grain, maintained under optimal conditions for pest development (15% moisture content and 25°C), with predator-to-prey ratios of 0, 0.02, 0.04, and 0.1.

Regarding the results, after 21 days, pest and predator densities were evaluated. Their findings revealed that *C. malaccensis* successfully consumed all five tested mite species and some eggs of *T. castaneum*, but did not prey on *E. kuehniella* eggs, indicating a mainly acarophagous predatory habit. At lower initial predator-to-prey ratios, the population of *C. malaccensis* grew most significantly when feeding on *C. redickorzevi*, *A. ovatus*, or *L. destructor*, with less pronounced growth on *A. siro* or *T. putrescentiae*. Consistent with these growth patterns, the highest control efficacy was observed against *A. ovatus* and *L. destructor*. Based on these results, the authors concluded that *C. malaccensis* functions as an oligophagous predator of pest mites, making it a suitable candidate for biological control programs.

Palyvos and Emmanouel (2009) investigated how varying temperatures affect the development of *C. malaccensis*, providing key insights into its temperature-related growth patterns. They specifically examined the effects of temperature on the immature stages of *C. malaccensis*, comparing offspring from both fertilized and virgin females across a temperature range of 17.5–35°C. Their findings revealed critical thermal thresholds for development, with lower and upper limits estimated at 11.6-12.0°C and 37.4-37.8°C, respectively, while the optimal developmental temperature fell between 33.1-33.5°C. The study provided evidence of arrhenotokous parthenogenesis in *C. malaccensis*, as unmated females produced exclusively male progeny, while fertilized females gave rise to both male and female offspring. Additionally, survival rates were highest at 25°C, though temperature did not significantly alter sex ratios or overall immature survival.

Following the initial study published in 2009 on the temperature-dependent development of *C. malaccensis*, Palyvos and Emmanouel (2011) expanded their research to include additional aspects such as reproductive performance, survival, and life table parameters of this predatory mite. Their extended study systematically assessed *C. malaccensis* at six constant temperatures (17.5, 20, 25, 30, 32.5, and 35°C), utilizing *T. putrescentiae* as the primary prey. The results from the study revealed that the pre-oviposition period for both fertilized and virgin females exhibited a temperature-dependent response, shortening from approximately 9 days to about 1.5 days at 17.5°C and 32.5°C, respectively, before a slight increase at 35°C. A notable finding was the significantly shorter oviposition duration observed in virgin females compared to their fertilized counterparts across most temperatures, with the exception of 17.5°C.

Detailing the reproductive output, peak total fecundity occurred at 30°C, yielding an average of 169.7 ± 6.6 eggs per fertilized female and 60.7 ± 4.3 eggs per virgin female. The data highlighted a substantial and nearly twofold positive impact of fertilization on female fecundity within the examined temperature range, excluding 17.5°C. Age-specific fecundity modelling revealed a maximum daily egg production of 10.3 eggs for fertilized females (30°C) and 6.8 eggs for unmated females (32.5°C). Palyvos and Emmanouel also observed that virgin females generally had shorter longevity than fertilized females, with overall longevity exhibiting an inverse relationship with temperature. The findings indicated that the intrinsic rate of increase (r_m) of *C. malaccensis* rose steadily from 0.03/day at 17.5°C to a peak of 0.21/day at 32.5°C, before declining to 0.15/day at 35°C.

In a study conducted in the Hail region of Saudi Arabia, Al-Shammery (2014) surveyed stored product facilities and identified several predatory mite species co-occurring with common insect and mite pests. Among these, *Cheyletus malaccensis* Oudemans emerged as the most frequently encountered predatory mite. The research evaluated the developmental biology of *C. malaccensis* when reared on three acarid mite pests, viz., *Tyrophagus putrescentiae*, *Caloglyphus rodriguezi*, and *Acarus siro*, alongside the insect prey *Ephestia kuehniella*. Under controlled conditions (26°C and 65% relative humidity), *C. malaccensis* displayed markedly better development and reproductive output when fed on *T. putrescentiae*, followed by *C. rodriguezi*, whereas feeding on *A. siro* resulted in the least favorable outcomes. Notably, when utilizing *T. putrescentiae* as a food source, the predator exhibited a significantly higher rate of population doubling, net reproductive rate, and intrinsic and finite rates of increase. While *C. malaccensis* is well known for its role in managing mite pests, the study also revealed its capacity to control insect pests, suggesting a wider applicability in stored product pest management strategies.

Metwalley et al. (2015) examined how varying thermal conditions influence the biological performance of *Cheyletus eruditus* when fed on different developmental stages of *Acarus siro*. The study compared the predator's development at 20 °C and 30 °C, revealing that lower temperatures prolonged all key biological parameters. For instance, the incubation period was notably extended at 20 °C, reaching up to 8.3 days in males feeding on immature prey, whereas it dropped to 4.4 days at 30 °C when males consumed eggs. Female life cycle duration also followed this temperature-dependent pattern, lasting 30.7 days at 20 °C and shortening to 19.1 days at 30 °C when fed on *A. siro* eggs. Fecundity was highest when females consumed eggs at 30 °C, averaging nearly 50 eggs, while feeding on immature stages at 20 °C resulted in the lowest egg production (33 eggs). Predation rates also reflected this variation as female predators consumed up to 436 prey eggs over their lifespan at 30 °C, while males showed significantly lower consumption.

Understanding the factors that shape the life history traits of predatory mites is crucial for their effective deployment in biological control. In this context, Omar et al. (2016) conducted an experiment investigating the influence of various developmental stages of *Tetranychus cucurbitacearum* on the developmental time, consumption rate, and fecundity of

C. malaccensis. Their studies were conducted under controlled conditions (32 ± 2°C and 50 ± 10% RH), and results revealed a notable influence of prey stage on most biological parameters, with the exception of the incubation period across both sexes. Female *C. malaccensis* consistently exhibited a longer life cycle than males, with specific developmental durations varying depending on the prey stage consumed. They found adult female longevity reached 52.4 days when feeding on eggs, which was a considerably longer period compared to males (18.9 days) on the same diet. The study also revealed that both the quantity of prey consumed and the fecundity of *C. malaccensis* were significantly lower when it was sustained on the immature and adult stages of *T. cucurbitacearum*, compared to when it fed on the egg stage of the same prey.

The poultry industry is often vulnerable to significant economic losses caused by infestations of parasitic mites. Such infestations adversely affect bird health, compromise egg quality, and reduce overall productivity, thereby highlighting the need for effective and sustainable control strategies. In this context, Granich et al. (2016) evaluated the predatory efficacy of *Cheyletus malaccensis* against *Tyrophagus putrescentiae* and *Megninia ginglymura* under controlled laboratory conditions (25 ± 1°C, 80 ± 5% RH, 12-hour photoperiod). Their results demonstrated that *C. malaccensis* had superior biological performance on *M. ginglymura*, showing higher fertility, prolonged oviposition periods, and enhanced population growth parameters (R_0, r_m, λ). Although both prey species supported high survivorship during immature development, the predator's life cycle was shorter when feeding on *T. putrescentiae*. Behavioural observations, including shelter-seeking egg-laying and maternal guarding, further supported *C. malaccensis* as a potent biocontrol agent, particularly against *M. ginglymura* in poultry systems.

While numerous predatory mites from the order Trombidiformes, particularly those in the families Cheyletidae, Stigmaeidae, and Cunaxidae, have been extensively studied for their role in the biological control of stored product pest mites, there is also a need to consider and examine other effective predatory mite groups. Among these, certain mesostigmatid mites, particularly *Blattisocius dentriticus,* have shown considerable potential. Silva et al. (2016) conducted a detailed evaluation of *B. dentriticus* as a prospective biological control agent against two mite species of established public health significance, namely *Tyrophagus putrescentiae* and *Megninia ginglymura*. Under controlled laboratory conditions (25 ± 1°C, 80 ± 5% relative humidity, in darkness), their investigation detailed the developmental time, reproductive parameters, survival rates, and sex ratio of this predatory mite when sustained on these two distinct prey species.

Concerning its performance, a notable finding was the significantly extended pre-oviposition period observed when *M. ginglymura* served as prey, contrasting with the shorter period on *T. putrescentiae*. Analysis of life-table parameters distinctly illustrated the superior demographic performance of *B. dentriticus* when feeding on *T. putrescentiae*. On this diet, the population exhibited a net reproductive rate of 7.53 and with a mean generation time of 14.3 days. This translated to a daily population growth rate of approximately 1.15. In stark contrast, individuals sustained on *M. ginglymura* displayed considerably lower demographic values, including a net reproductive rate of 2.79, a protracted mean generation time of 23.76 days and a daily growth rate of 1.04. These results confirm the capacity of *B. dentriticus* to develop and reproduce successfully on both *T. putrescentiae* and *M. ginglymura*, but clearly establish its more robust performance when *T. putrescentiae* is the primary food source.

Investigating the biological traits of *C. malaccensis* when preying on the poultry red mite, *Dermanyssus gallinae*, Toldi et al. (2017) explored the influence of varying temperatures on this predatory relationship. Their study commenced with individual eggs of *C. malaccensis*, each isolated in an experimental unit and allowed to develop through all life stages while exclusively consuming *D. gallinae*. Experiments were conducted across three distinct temperatures: 20°C, 25°C, and 30 ± 1°C, consistently maintained at 80 ± 5% relative humidity. It is noteworthy that the adult females that emerged were unmated, resulting in arrhenotokous reproduction (producing only male offspring).

Regarding the results, the reproductive output demonstrated a clear temperature dependency in which fecundity peaked at 25°C (415.62 ± 24.78 eggs/female), while the lowest rates were observed at 20°C, with a slight increase at 30°C. Interestingly, the mean generation time of *Cheyletus malaccensis* did not exhibit significant differences across the three tested temperatures. However, key population parameters, including the net reproductive rate, the intrinsic rate of increase, and the finite rate of increase, were found to be significantly higher at 30°C and notably lower at 20°C. These findings collectively indicated that *Cheyletus malaccensis* possesses the capacity to successfully develop and reproduce when feeding exclusively on *Dermanyssus gallinae*. Their study concluded that 25°C represented the optimal temperature for the overall development, fertility, and survival of *C. malaccensis* under these conditions.

Liu et al. (2018) examined the developmental progression of *C. malaccensis* maintained at a fixed temperature of 24°C under a range of relative humidity levels (65 ± 2%, 75 ± 2%, 85 ± 2%, and 95 ± 2% RH). Their study used *Acarus siro* as the sole prey source. The findings revealed that *C. malaccensis* progresses through five distinct developmental stages; egg, larva, protonymph, deutonymph and adult, with the deutonymph stage notably absent in males. For females, the shortest developmental time from egg to adult (16.3 days on average) was observed at 85 ± 2% RH, while the longest (18.6 days) occurred at 65 ± 2% RH. In contrast, male mites exhibited their quickest developmental period (12.6 days on average) at 95 ± 2% RH, extending to 14.7 days at 65 ± 2% RH.

Regarding reproductive and longevity metrics, adult male longevity reached 83.5 days at 95 ± 2% RH, resulting in an egg-to-adult longevity of 95.8 days. Their study demonstrated that humidity exerted a significant influence on both adult lifespan and the duration of all developmental stages. They documented the maximum average fecundity (493.0 eggs per female), longest oviposition period (46.2 days), and highest daily fecundity (10.3 eggs) at 85 ± 2% RH.

Zhu et al. (2019) explored the functional response of adult *C. malaccensis* against various developmental stages of its prey, *Aleuroglyphus ovatus*, under five constant temperature regimes (16, 20, 24, 28, and 32°C). Within the evaluated temperature range, female *C. malaccensis* demonstrated a higher consumption rate of larval and nymphal stages of *A. ovatus*, followed by adult males and females, while exhibiting minimal consumption of eggs. In contrast, male *C. malaccensis* primarily consumed only larval and nymphal prey. Their study further revealed that both daily consumption and the instantaneous attack rate generally increased with rising temperatures from 16°C to 32°C, peaking notably at 28°C. The study noted preferential feeding patterns, with *C. malaccensis* positively favouring larvae and nymphs, but negatively selecting adult and egg stages of *A. ovatus*. Zhu et al. also observed that increasing predator density led to a decrease in predation efficiency, likely due to heightened competition and interference among predators.

Sun et al. (2020) conducted a detailed study to explore how temperature influences the population growth dynamics of *Cheyletus malaccensis* within grain storage facilities in China. They constructed age-stage, two-sex life tables for *C. malaccensis* using *A. siro* as prey under laboratory conditions at five different temperatures (22°C, 24°C, 28°C, 30°C, and 32°C), a constant relative humidity of 75%, and a 24-hour dark period. Their findings demonstrated a clear impact of temperature on development, as increasing temperatures generally shortened the developmental time of immature stages. The complete generation time for *C. malaccensis* varied significantly, ranging from 11.10 days to 27.50 days. Importantly, the life table parameters indicated that 28°C was the optimal temperature for the growth and development of *C. malaccensis*, facilitating rapid population increases. This temperature also yielded the highest net reproductive rate (290.25) and the highest fecundity (544.52 eggs). The study further confirmed that temperature significantly influenced the intrinsic rate of increase, fecundity, and finite rate of increase. Analysis of age-specific fecundity revealed a peak at 28°C, followed by 24°C, 30°C, 32°C, and 22°C. These results provide important information into the thermal requirements for maximizing *C. malaccensis* population growth.

Building upon the existing knowledge base established in prior works, Elhalawany et al. (2022) recently conducted a comprehensive laboratory investigation into the biological parameters and life table characteristics of *Cheyletus malaccensis*. Their study specifically examined the performance of *C. malaccensis* when preying on three distinct astigmatid mites, viz., *A. siro*, *Caloglyphus berlesei*, and *T. putrescentiae* under various temperatures (22°C, 27°C, and 32 ± 2°C) and a consistent 80 ± 5% relative humidity. Statistical analysis of their collected data revealed significant interactions between prey type and temperature conditions. The shortest life cycle for *C. malaccensis* was observed when fed on *A. siro* at 32°C (11.60 days for females, 8.0 days for males), while the longest occurred on *C. berlesei* at 22°C (29.5 days for females, 21.2 days for males).

Detailing key results, female longevity was maximized on *A. siro* at 22°C (43.6 days) but was notably shorter on *T. putrescentiae* at 32°C (20.65 days). In terms of reproduction, *C. malaccensis* achieved its highest fecundity (196.50 eggs per female) when *A. siro* served as prey. The lowest fecundity was recorded on *C. berlesei* at 22°C (69.10 eggs per female). These findings collectively suggest that *C. malaccensis* possesses the capacity to develop and reproduce across a broad spectrum of temperatures and with various prey species.

Similar to *Cheyletus malaccensis*, the Mesostigmatid mite *Blattisocius mali* also demonstrates significant potential as a biological control agent against pest mites. Asgari et al. (2022) evaluated the performance of *B. mali* when fed on different life stages of *T. putrescentiae* under controlled laboratory conditions. Their study demonstrated that prey stage significantly influenced predator performance. Feeding on larvae led to a markedly higher reproductive output, with a 2.6-fold increase in fecundity compared to feeding on eggs. The intrinsic rate of increase (*r*) was also notably greater when larvae were provided (0.357/day) versus eggs (0.272/day), indicating enhanced suitability of larvae for predator population growth. Although mean generation time remained statistically similar across prey types, overall reproductive metrics such as the net reproductive rate and finite rate of increase followed the same trend. Interestingly, despite better reproductive outcomes on larvae, feeding on eggs resulted in higher predation and prey-to-offspring conversion rates. From a practical standpoint, these findings suggest that *B. mali* can effectively exploit both prey stages for pest suppression, though larval prey may be preferable for mass-rearing and augmentation efforts. The results suggest that mesostigmatid mites like *B. mali* could be effectively integrated alongside established predators in comprehensive biological control strategies for stored product ecosystems.

The management of psocid pests in stored products presents a considerable challenge, particularly given their resilience even to potent pesticides like phosphine. In light of this, recent research has explored the efficacy of predatory mites as a sustainable biological control alternative. Danso et al. (2023) quantitatively assessed the biological control potential of two prominent Cheyletid mites viz., *Cheyletus malaccensis* and *Cheyletus eruditus* against the psocid species *Liposcelis decolor*. Their laboratory investigation, conducted over 40 days under various predator-to-prey ratios (ranging from 0:20 to 10:20), temperatures (20°C, 24°C, 28°C, and 32°C), and relative humidities (63%, 75%, and 85%), focused on evaluating prey population suppression and predator progeny replacement efficiency.

Summarizing the findings, their results clearly demonstrated that both *C. eruditus* and *C. malaccensis* were capable of surviving, establishing, and producing significant numbers of offspring when preying on *L. decolor*, with population increases ranging from approximately 96.7% to 844.4% fold. Critically, these predatory mites achieved substantial suppression of *L. decolor* populations, with reduction rates varying between 67.1% and 97.2%. Notably, *C. malaccensis* exhibited slightly higher suppression efficacy, reaching up to 96.5% at the highest predator-to-prey ratio (10:20), compared to the peak performance of 87.5% by *C. eruditus*. Although lower relative humidity (63% RH) marginally limited their effectiveness, the consistent and robust performance of both predatory species across a wide range of thermo-hygrometric conditions underscores their considerable promise as biocontrol agents.

In a recent investigation, Arco et al. (2024) evaluated the efficacy of three predatory mite species, *Amblyseius swirskii*, *Blattisocius tarsalis* and *Cheyletus malaccensis*, in managing insect pests commonly found in stored cereal grains. Their experiments, which involved offering a controlled number of prey items to mite females in different arena settings, evaluated prey acceptance and predation rates. The findings indicated that both *B. tarsalis* and *C. malaccensis* exhibited broad polyphagous behavior, preying effectively on insect pests frequently encountered in stored rice and other cereals. Conversely, *A. swirskii* demonstrated negligible efficacy against these target pest species.

Regarding their practical application, Arco et al. (2024) further investigated the effectiveness of *B. tarsalis* and *C. malaccensis*, both individually and in combination, in suppressing populations of *Oryzaephilus surinamensis* and *Sitotroga cerealella* within medium-sized arenas. In all tested scenarios, whether applied singly or together, these predatory mites consistently achieved a reduction of approximately fifty percent in the populations of *O. surinamensis* or *S. cerealella*. These compelling results collectively suggest that strategic, periodic releases of *B. tarsalis* and *C. malaccensis* hold significant potential for maintaining pest populations below economically damaging thresholds in stored cereal environments.

2.2.2 Research from India

The family *Cheyletidae* includes several predatory mite species with promising potential for biological control; however, their pest suppression capabilities remain relatively underexplored, particularly in India, despite being taxonomically studied to a considerable extent. Contributing to the broader understanding of cheyletid biology, Mathur and Minocha (1989) reported cannibalistic behavior in populations of the predatory mite *Acaropsis sollers*, observed among both immature and adult individuals. Their findings revealed that the incidence of cannibalism was influenced by the density and developmental stage of available prey. Furthermore, the predator showed a marked preference for consuming eggs and early instars rather than mature individuals. Based on these behavioural patterns, *A. sollers* was suggested to hold promise as a biological control agent against *Trogoderma granarium*, a major pest of stored products.

Singh (1984) examined the developmental biology and predatory feeding behavior of *Acaropsis docta*, when offered *Rhizopertha dominica* as prey on stored wheat. The study quantified prey consumption across life stages, reporting average daily intake rates of 1.19 eggs for larvae, 1.30 for protonymphs, and 1.48 for deutonymphs. Among adults, females exhibited higher predation rates, consuming approximately 1.62 eggs per day, whereas males consumed significantly fewer, averaging 0.52 eggs daily. Based on these observations, the study highlighted the potential of *A. docta* as an effective biological control agent for managing *R. dominica* populations in stored grain environments.

Mathur and Dalal (1989) conducted a laboratory investigation to assess how variations in diet influence the development and reproductive performance of *Suidasia nesbitti*. Their findings indicated that wheat germ supported the most rapid development from larval to adult stage, with the shortest developmental duration recorded at 9.68 days. This diet also resulted in the highest fecundity and the largest adult body size. In contrast, developmental time increased noticeably when the mites were reared on diets lacking starch and sucrose. Mortality rates across immature stages were lowest on wheat germ, while egg mortality peaked when mites were reared on grain residue alone. Additionally, the combined presence of residue, sucrose, and starch resulted in elevated mortality among larval, protonymph, and tritonymph stages. Based on these experimental observations, wheat germ clearly emerged as the most favorable food source for promoting both survival and optimal development in *S. nesbitti*.

Adding to existing knowledge of predator–prey relationships in stored grain environments, Kumar and Naqi (1990) investigated the interactions involving *Acaropsis sollers* and *Cheyletus malaccensis* under laboratory conditions. When both species were introduced into grain infested with *Trogoderma granarium* and *Rhyzopertha dominica*, the predators actively fed on mite stages and pest eggs. Notably, *A. sollers* exhibited cannibalistic behavior over time, consuming not only *C. malaccensis* but also its own eggs after a prolonged exposure period. Despite this, the study highlighted *A. sollers* as a potential biocontrol agent due to its predation on economically significant insect pests. Such findings underscore the complexity of predator-prey interactions among cheyletid mites and suggest that further investigation into their intra-guild dynamics and host preferences could contribute valuable insights into the development of sustainable pest management strategies.

Nangia and ChannaBasavanna (1990) conducted a laboratory study focusing on the developmental biology of *Cheyletus malaccensis* at 24 ± 1°C and 80% relative humidity, using *Tyrophagus putrescentiae* as the prey species. Their results demonstrated an incubation period of 6±0.05 days (88.6% hatchability), with larval, protonymphal, and deutonymphal stages lasting 3 ± 0.5, 4 ± 0.5, and 4 ± 0.5 days respectively. The reported fecundity (37 ± 0.2 eggs per female) was found to be considerably lower than the values obtained in several subsequent studies that used the same prey species, suggesting potential influences arising from differing experimental conditions or underlying population-level differences. Notably, males showed greater longevity (42 ± 0.5 days) than females (37 ± 5.6 days), contrasting with later findings, while the sex ratio remained balanced (1:1). The study's most distinctive contribution was its documentation of cannibalistic behavior in *C. malaccensis*, a phenomenon that warrants further investigation under varying ecological conditions. These early findings provide important baseline data, yet the observed discrepancies with later research highlight the complex interplay between biotic factors (e.g., prey quality) and abiotic conditions in shaping the predator's life history traits.

While Nangia and ChannaBasavanna (1990) reported basic biological parameters under limited conditions, Mukherjee (2012) later conducted a more comprehensive examination of temperature effects on *C. malaccensis* development in her doctoral thesis under two controlled temperature regimes: 25 ± 1°C and 30 ± 1°C, with a constant relative humidity of 85 percent and *Tyrophagus putrescentiae* as the prey mite. The study revealed a clear temperature-dependent acceleration in the life cycle. The total developmental duration from egg to adult was significantly shorter at the higher temperature, decreasing from 24.6 ± 0.5 days at 25°C to 16.5 ± 0.3 days at 30°C. Similar trends were observed across all immature stages. The incubation period decreased from 4.7 ± 0.2 to 2.76 ± 0.1 days, the larval period from 7.2 ± 0.2 to 4.6 ± 0.1 days, the protonymph stage from 6.5 ± 0.2 to 5.1 ± 0.1 days, and the deutonymph stage from 6.1 ± 0.2 to 4 ± 0.1 days at 25°C and 30°C, respectively.

Regarding reproductive and demographic outcomes, fecundity levels were notably high with females laying approximately 223 to 225 eggs, which exceeded values reported in previous studies. Female longevity was also greater than that of males with average female lifespans recorded at 29.5 ± 0.3 days at 25°C. Furthermore, the population exhibited a female-biased sex ratio, which varied with temperature: 6.6 to 1 at 25°C and 4.5 to 1 at 30°C.

Suidasia nesbitti has emerged as a persistent pest in stored grain systems, with a global presence across tropical and subtropical regions. Devi et al. (2022) reviewed its biological and ecological traits, highlighting its preference for substrates rich in protein and fat, such as broken grains, flour, and yeast-based materials. The mite's reproductive success is closely related to environmental conditions, particularly high humidity and warm temperatures, which can accelerate its life cycle to as little as 7 to15 days. Infestations have been linked to considerable damage, including reduced nutritional content and lowered germination capacity of stored seeds. Notably, germination loss in pulses and cereals such as Bengal gram and pearl millet has reached over 70% during prolonged storage. The species also exhibits a hypopial stage, enabling survival under adverse conditions and contributing to its persistence in storage environments. Control strategies suggested include maintaining low humidity and exploring botanical alternatives to chemical treatments.

Several studies in India have examined the taxonomy and developmental biology of pest mites associated with stored products, yet research on predatory mites for biocontrol remains limited. The family Cheyletidae, particularly *Cheyletus malaccensis*, has demonstrated significant potential for biocontrol, yet it remains understudied in India. While this species has been well-documented internationally, research within the country is limited to scattered records from northern regions, with no published studies from Kerala or southern India. Most Indian reports have primarily noted its occurrence and role as a beneficial predator in stored products, rather than conducting detailed investigations into its developmental biology, physiology, or biocontrol potential.

Outlining the research gap, variations in its developmental biology across studies suggest possible influences from experimental conditions or regional biotypes, highlighting the need for localized investigations. Given India’s rich biodiversity and the growing demand for sustainable pest management, advancing research on this predator’s biology, mass rearing, and field efficacy is critical. The present study addresses these gaps by generating region-specific developmental data, refining rearing protocols, and evaluating feeding biology to support its practical application in stored product protection.

CHAPTER III

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The methodology employed in the present study is divided into two distinct parts. Part I comprises of the faunistic survey, taxonomy, and identification of predatory mites. Part II focuses on the breeding and feeding biology and mass-rearing protocols of the predatory mite *Cheyletus malaccensis*, using the prey mite *Suidasia nesbitti*.

3.1. Part I- Survey, Taxonomy and Identification

3.1.1. Collection sites

A total of 61 storage facilities located across 6 districts of North Kerala were surveyed, including samples collected from domestic residences (Plate 1). Details of the stored products and the species obtained from each facility are presented in Table 1 and 2.

Kasaragod

1. Nileshwar (12° 15' 27.84" N, 75° 08' 05.60" E) - Food Corporation of India.

2. Thrikaripur (12° 8' 40" N, 75° 10' 15" E) - Household.

3. Kanhangad (12°17'20.1" N75°08'05.7" E) - Household.

4. Kasaragod (12° 30' 10" N,74° 59' 20" E) - Supplyco district depot.

5. Hosdurg (12° 38' 34.82" N, 74° 55' 35.24" E) - Dry fruits store.

6. Manjeshwar (12° 43' 30.08" N, 74° 53' 08.05" E) - Supplyco store.

7. Kadumeni (12°17'25.4"N 75°20'41.9"E) - Household.

8. Kanhagad (12° 18' 36" N,75° 5' 30" E) - State Warehousing Corporation.

9. Kanhagad (12° 18' 35" N, 75° 5' 29" E) - Supplyco taluk depot.

Kannur

1. Cherupuzha (12° 16' 29.58"N,75° 21' 51.39" E) - Supplyco supermarket.

2. Dharmashala (11° 58' 59" N, 75° 22' 36" E) - Central Warehousing Corporation.

3. Dharmashala (11° 58' 59" N, 75° 22' 36" E) - Supplyco PDS depot.

4. Payyannur (12° 05' 02.52" N, 75° 11' 58.56" E) - Food Corporation of India.

5. Payyannur (12° 06' 34.36" N, 75° 13' 07.43" E) - Grocery store.

6. Thalipparamba (12° 02' 28.34" N, 75° 21' 21.52" E) - Supplyco depot.

Kozhikode

1. Town (11° 14' 56.4" N, 75° 46' 38.0" E) - Market Warehouse, Market-Grocery store.

2. Chelannur (11° 22' 03.1" N, 75° 47' 39.5" E) - Household.

3. West Hill (11° 17' 14.0" N, 75° 45' 56.0" E) - Food Corporation of India.

4. West Hill (11° 17' 0" N, 75° 45' 43" E) - Central Warehousing Corporation.

5. Beach Road (11° 16' 12.05" N, 75° 46' 03.4" E) - Supplyco Sub depot.

6. Thamarassery-Vavad (11° 23' 26" N, 75° 55' 18" E) - Supplyco depot.

7. Thamarassery-Paalakkutty (11°22'16.2"N 75°54'33.4"E) - Supplyco depot.

8. Kozhikode (11° 17' 37.8" N, 75° 48' 15.6" E) - Grocery Store.

9. Chethukadavu (11° 18' 46.5" N,75° 54' 8.9" E) - Household.

10. Atholi (11° 22' 7" N,75° 45' 9" E) - Household.

11. Thikkodi (11° 29' 40" N,75° 37' 34" E) - Food Corporation of India.

12. Thalakkulathur (11° 22' 07.25" N, 75° 45' 12.74" E) - Household.

13. Velur (11° 24' 15" N, 75° 45' 48" E) - Oil mill.

14. Kunnathara (11° 24' 56" N, 75° 46' 6" E) - Copra processing unit.

15. Parambath (11° 21' 18.43" N, 75° 45' 31.15" E) - Supplyco supermarket.

16. Koliyotuthazham (11° 22' 2" N, 75° 45' 28" E) - Flour mill.

17. Quilandy (11° 26.933' N, 75° 42.3' E) - Household.

Wayanad

1. Bathery (11° 39' 13.51" N, 76° 15' 28.07" E) - Supplyco PDS depot.

2. Mananthavady (11° 45' 7" N, 76° 0' 33" E) - Spice store.

3. Meppadi (11° 33' 24.5" N, 76° 07' 53.23" E) - Spice store.

4. Kalpetta (11° 36' 53" N,76° 4' 25" E) - State Warehousing Corporation

5. Kalpetta (11° 37' 36.2" N, 76° 04' 15.3" E) - Supplyco depot.

6. Meeanangadi (11°39'18.6"N 76°09'22.2"E) - Food Corporation of India.

Malappuram

1. Kuttippuram (10° 50' 42.00" N, 76° 02' 04.76" E) - Food Corporation of India.

2. Angadippuram (10°58'55.4"N 76°12'34.3"E) - Food Corporation of India.

3. Angadippuram (10° 58' 44.54" N, 76° 12' 27.14" E) - Supplyco depot.

4. Manjeri (11° 06' 35.83" N, 76° 07' 15.03" E) - Supermarket.

5. Manjeri (11° 08' 04.16" N, 76° 06' 51.41" E) - State Warehousing Corporation.

6. Manjeri (11° 07' 14.93" N, 76° 07' 10.52" E) - Supplyco supermarket.

7. Nilambur (11° 16' 27" N, 76° 14' 6" E) - Household.

8. Makkaraparamba (11° 01' 00.20" N, 76° 07' 26.15" E) - Household.

9. Parappanangadi (11° 03' 03.25" N, 75° 51' 24.21" E) - Private warehouse.

10. Tirur (10° 54' 55.89" N, 75° 55' 21.21" E) - Grocery store.

11. Thanur (10° 58' 34.21" N, 75° 52' 43.29" E) - Supplyco supermarket.

Palakkad

1. Vadakkanthara (10° 46' 25.88" N, 76° 38' 53.55" E) - Supplyco supermarket.

2. Puthuppariyaram (10° 48' 28.63" N, 76° 37' 44.74" E) - Food Corporation of India.

3. Kalvakulam-Mankavu (10° 46' 25.51" N, 76° 40' 02.66" E) - Supplyco taluk depot.

4. Thayilpetti (10° 45' 59.96" N, 76° 39' 17.02" E) - State Warehousing Corporation.

5. Sultanpet (10° 46' 15.40" N, 76° 39' 30.41" E) - Supermarket.

6. Melamuri (10° 46' 25.25" N, 76° 38' 26.61" E) - Supermarket.

7. Valiyangadi (10° 46' 25.27" N, 76° 38' 46.83" E) - Market-Grocery store.

8. Kanjikode (10° 47' 14.69" N, 76° 47' 07.67" E) - Central Warehousing Corporation.

9. Thekkenkunam (10° 47' 23.08" N, 76° 41' 39.12" E) - Flour mill.

Due to site specific restrictions, photography at the collection locations, namely warehouses managed by the Food Corporation of India (FCI), Central Warehousing Corporation (CWC), State Warehousing Corporation (SWC), and Kerala State Civil Supplies Corporation (Supplyco), was strictly prohibited. Specimen collection was conducted only after submitting formal applications and obtaining necessary approvals through official channels, including board level permissions where applicable. In compliance with the conditions set by these agencies, visual documentation has been intentionally omitted to meet ethical and legal obligations.

3.1.2. Stored products surveyed

A total of 63 types of stored products, including cereals, pulses, spices, oil seeds, dried nuts, dried fruits, dried fish, edible mushrooms, dried ginger, garlic, etc., were surveyed from the different sampling localities. Details are provided in Table 1.

3.1.3. Collection of samples

Prior to sampling, each storage facility was carefully inspected for mite infestation indicators, such as storage pest insects and elevated moisture content. Stored products exhibiting suspected signs of infestation were then randomly sampled from various spots within the same facility.

Samples were collected using three methods:

1. Extracting material from gunny bags using a poker.
2. Sweeping grains and residues from the floor with a wide plastic brush and pan.
3. Directly scooping samples from open bags using a sterile stainless-steel scoop.

Infested stored product samples from domestic residences were collected solely based on homeowner provision. Due to limitations regarding access to private dwellings, samples were restricted to those willingly offered by homeowners. No alternative sampling methods within these residences were applied. Collection of stored product samples was done according to the availability at storage facilities. From each location, multiple samples (approximately 100g each) of the same commodity were gathered, then sealed in plastic zip-lock bags (Fig. 1 of Plate 2). GPS coordinates were recorded for each storage facility using Google Maps.

3.1.4. Extraction of mites

Collected samples were transported to the laboratory. Prior to Berlese funnel extraction, a subset of samples from each packet was examined using a Magnus stereozoom microscope (Fig. 2 of Plate 2). This preliminary step was crucial to identify and preserve mite species that would not survive heat desiccation method. Mites recovered during this examination were then transferred to vials containing 70% ethanol using a wetted camel hair brush. Following the preliminary examination, all samples were subjected to Berlese-Tullgren funnel extraction using 60W incandescent bulbs (Fig. 3 of Plate 2). Extracted mites were collected in containers filled with 70% ethanol, which were placed at the base of each funnel. The resulting ethanol solution, containing the extracted mites was then collected and stored in vials prior to slide preparation.

3.2. Taxonomic studies and identification of specimens

3.2.1. Preparation of specimens

A) Dehydration and clearing of specimens

Mite specimens preserved in 70% ethanol were dehydrated through an ascending alcohol series (80%, 90%, and absolute ethanol). Dehydrated specimens were then cleared using a 1:1 solution of lactic acid and absolute ethanol. Clearing duration varied based on the level of sclerotization of specimens, ranging from 5 minutes to 1-2 days. Specimens were temporarily placed in cavity blocks or stored in Eppendorf tubes containing clearing solution during the clearing process. Following clearing, specimens were mounted on microscope slides in Hoyer's medium for taxonomic examination.

B) Preparation of Hoyer’s medium

Hoyer's medium is typically used for preserving and clarifying mite specimens for microscopic examination. This medium facilitates long-term preservation and enhances the visibility of delicate mite structures. The preparation includes four key ingredients:

1. Gum Arabic (Acacia powder): 30 g of Gum Arabic, also known as Acacia powder, was used as a mounting agent, providing a stable matrix for the specimens.

2. Chloral hydrate: 200 g of Chloral hydrate was incorporated as a clearing agent, rendering the mite tissues transparent and enhancing the visibility of internal structures.

3. Distilled water: 50 ml of distilled water was used as a solvent, ensuring the uniform dissolution of the other components.

4. Glycerol: 20 ml of Glycerol was added as a humectant, preventing the medium from drying out and preserving the specimen's integrity over time.

The above four components were weighed according to the required quantities and added to a 500 ml glass beaker. The mixture was gently warmed and continuously stirred using a magnetic stirrer for 24 hours, ensuring complete dissolution and the absence of clots. After cooling to room temperature, the solution was filtered through sterile cotton. The filtrate was then transferred to dark-coloured glass bottles for use in the mounting process.

C) Preparation of slide mounts of mite specimens

Dehydrated and cleared specimens were transferred to microscope slides containing a drop of Hoyer's medium using a fine camel hair brush with minimal bristles. This procedure, performed under a Magnus stereozoom microscope, ensured proper alignment and leg extension for optimal examination. Impurities or air bubbles within the Hoyer's medium were carefully removed with the brush. Cavity slides were utilized for bulged specimens to prevent rupture. Coverslips were applied using a needle, and slides were labelled with collection date, locality, source stored product, and slide preparation date. Mounted slides were dried either in an oven at 40-50°C for 5-6 days or under a 60W incandescent bulb at a 1-foot vertical distance for 2-3 days to enhance clearing (Fig. 4,5 of Plate 1). Dried slides were then sealed with transparent nail polish and stored in plastic slide boxes.

3.2.2. Documentation of measurements, photographs and illustrations

Microscopic observations of mounted specimens were conducted using an Olympus CX31 brightfield binocular microscope (Fig. 6 of Plate 1). Morphometric measurements were obtained using Lynx Biolux image analysis software (Lawrence and Mayo, India), with accuracy and calibration verified using an ocular micrometer. Digital specimen imaging was performed using an Olympus digital camera (Model E-PL3) equipped with a macroscopic lens. Hand-drawn illustrations were made using a drawing tube attached to the microscope. The manual illustrations were subsequently scanned, digitally redrawn, and converted into vector-based graphics using Adobe Illustrator (Adobe Systems Incorporated). All morphological measurements are reported in micrometers (μm) to ensure precision and standardization.

3.2.3. Morphological terminology for identification and description of species

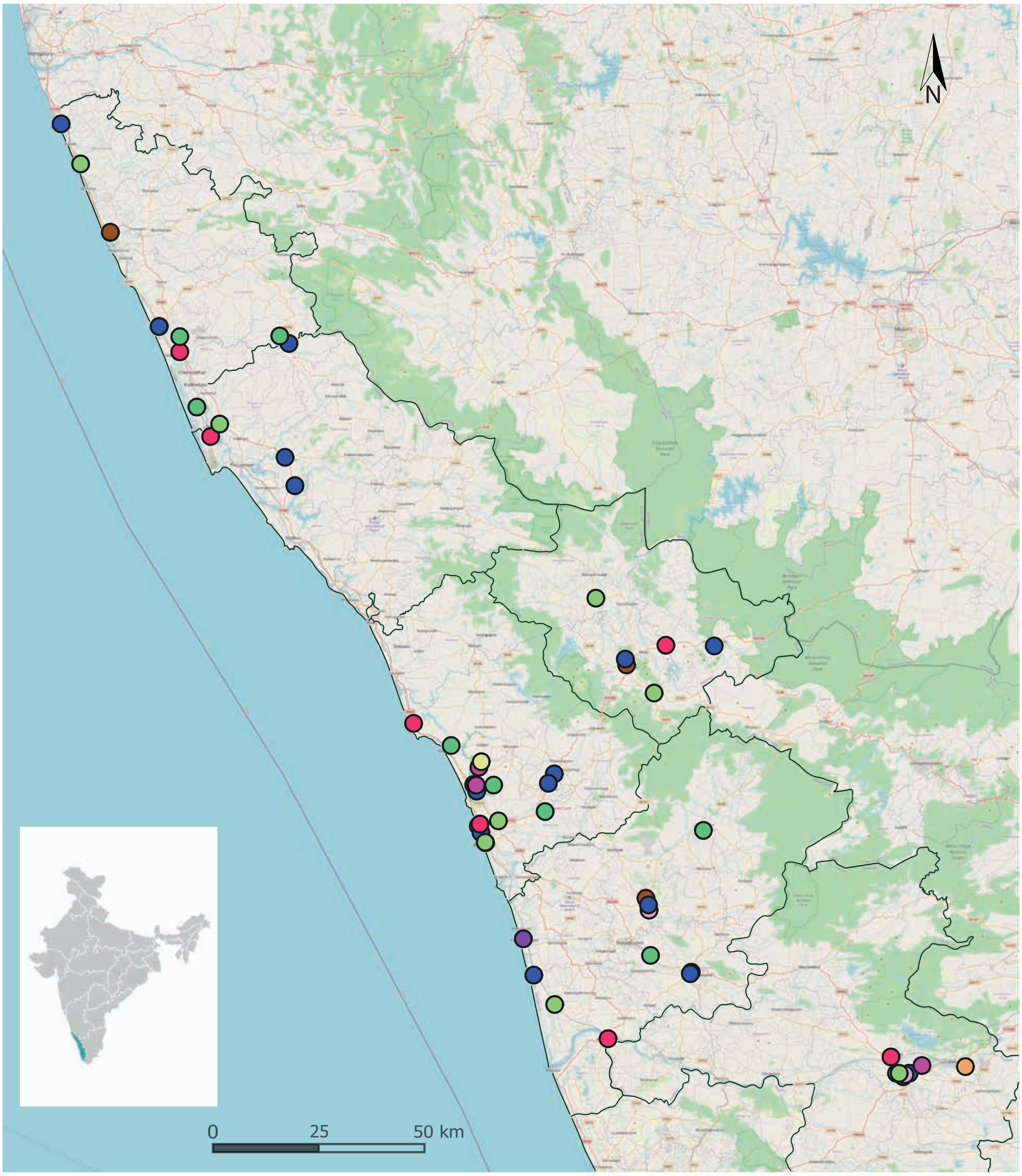
Morphological terminology and setal notations used in this study follow the standards established for each respective mite family. For the families *Blattisocidae* and *Melicharidae*, the dorsal and ventral body and setal notation follow Lindquist and Evans (1965) and Lindquist (1994). The same references, along with Lindquist et al. (2009) and Evans (1963), were used for *Laelapidae*. For *Phytoseiidae*, morphological terminology is based on Rowell and Chant (1978), Moraes et al. (2004), and Chant and McMurtry (2007). Terminology for *Sejidae* follows Hirschmann et al. (1991) and Lindquist and Evans (1965). For *Cunaxidae*, it is based on Fisher et al. (2011); for *Cheyletidae*, on Grandjean (1944) and Fain (1979); and for *Smarididae* and *Erythraeidae*, on Grandjean (1947) and Wohltmann et al. (2007). Morphological terminology for *Raphignathidae* is based on Fan and Zhang (2005), and for *Stigmaeidae*, on Fan et al. (2016). For *Bdellidae*, references include Kethley (1990), Den Heyer and Castro (2008), and Van der Schyff et al. (2003). In the case of *Caligonellidae*, terminology follows Kethley (1990), Norton (1977), and Swift (1996, 2001).

3.2.4. Identification of mite specimens

Identification of slide-mounted specimens, up to the superfamily and family levels, was achieved by comparing observed morphological characteristics with keys and illustrations in *A Manual of Acarology* (third edition) by Krantz and Walter (2009). Specimens were identified to the genus/species level using standard taxonomic literature, including Hughes (1976), Gupta (1985), Mary and Ramani (2009), and relevant research publications with appropriate taxonomic keys. For Mesostigmatid mites, primary references included the identification keys of Moraes *et al*. (2016) and Moraes *et al*. (2022). For Prostigmatid mites, keys from Fan and Zhang (2005) and Skvarla (2014) were primarily referred, along with supplementary research articles. Morphological characters were systematically compared with existing species descriptions in the referenced literature. Final species confirmation was conducted in consultation with leading acarologists worldwide.

PLATE 1

Figure 1. Geographical distribution of storage facilities surveyed from North Kerala



- Central Warehousing Corporation
- Food Corporation of India
- Grocery stores/ Spice stores
- Oil/ Flour Mill
- Private Supermarket
- Private Warehouse
- Processing Unit
- Residences (Household)
- State Warehousing Corporation
- Supplyco Warehouse/ Supermarket

TABLE 1. List of stored products surveyed and no. of predatory mite species obtained.

Sl. No.	Stored product	Number of predatory mite species obtained
1	Foxtail millet (*Setaria italica*)	5
2	Finger millet (*Eleusine coracana*)	2
3	Fenugreek (*Trigonella foenum-graecum*)	3
4	Wheat (*Triticum aestivum*)	7
5	Mustard (*Brassica nigra*)	6
6	Dried chilli (*Capsicum annuum*)	3
7	Black gram (*Vigna mungo*)	5
8	Green gram (*Vigna radiata*)	2
9	Broken rice (*Oryza sativa*)	2
10	Cumin seeds (*Cuminum cyminum*)	3
11	Lentils (*Lens culinaris*)	1
12	Arrow root powder (*Maranta arundinacea*)	1
13	Coriander (*Coriandrum sativum*)	3
14	Cardamom (*Elettaria cardamomum*)	1
15	Cinnamon (*Cinnamomum verum*)	1
16	Coffee beans (*Coffea arabica*)	1
17	Cashew nuts (*Anacardium occidentale)*	1
18	Dried asparagus (*Asparagus officinalis*)	1
19	Raisins (*Vitis vinifera*)	1
20	Garlic (*Allium sativum*)	1
21	Dried prawns (*Fenneropenaeus indicus*)	1

Sl. No.	Stored product	Number of predatory mite species obtained
22	Dried solefish (*Cynoglossus cynoglossus*)	1
23	Nutmeg (*Myristica fragrans*)	1
24	Oyster mushroom (*Pleurotus ostreatus*)	2
25	Peanut (*Arachis hypogaea*)	1
26	Rice flakes (*Oryza sativa*)	2
27	Soyabean (*Glycine max*)	1
28	Jaggery (*Saccharum officinarum*)	0
29	Wheat semolina (*Triticum turgidum*)	3
30	Corn semolina (*Zea mays*)	1
31	Dried ginger (*Zingiber officinale*)	1
32	Boiled rice (*Oryza sativa*)	11
33	Raw rice (*Oryza sativa*)	10
34	Green pea (*Pisum sativum*)	1
35	Basmati rice (*Oryza sativa*)	4
36	Pepper (*Piper nigrum*)	6
37	Chick pea (*Cicer arietinum*)	4
38	Cow pea (*Vigna unguiculata*)	1
39	Dried turmeric tuber (*Curcuma longa*)	0
40	Bamboo rice (*Bambusa arundinacea*)	1
41	Macroni (*Triticum durum*)	0
43	Dried kiwi (*Actinidia deliciosa*)	0
44	Dates (*Phoenix dactylifera*)	0

Sl. No.	Stored product	Number of predatory mite species obtained
45	Walnut (*Juglans regia*)	2
46	Almond (*Prunus dulcis*)	2
47	Clove (*Syzygium aromaticum*)	0
48	Raw cashew nuts (*Anacardium occidentale*)	1
49	Sesame (*Sesamum indicum*)	1
50	Sugar (*Saccharum officinarum*)	0
51	Black cumin seeds (*Nigella sativa*)	1
52	Broken brown rice (*Oryza sativa*)	2
53	Pearl millet (*Pennisetum glaucum*)	1
54	Pistachio (*Pistacia vera*)	0
55	Dried black lemon (*Citrus aurantifolia*)	1
56	Wheat flour (*Triticum aestivum*)	1
57	Fortified rice (*Oryza sativa*)	1
42	Brown rice (*Oryza sativa*)	1
59	Fennel seeds (*Foeniculum vulgare*)	2
60	Copra (*Cocos nucifera*)	2
61	Coffee beans with pod (*Coffea arabica*)	0
58	Rice powder (*Oryza sativa*)	2
62	Dried fig (*Ficus carica*)	0
63	Horse gram (*Macrotyloma uniflorum*)	1

PLATE 2

Figure 1-6. Materials and Methods

1. Collected stored product samples sealed in zipper bags.

2. Direct mite extraction under stereozoom microscope.

3. Mite extraction using Berlese–Tullgren funnel apparatus.

4. Drying of microscopic slides in hot air oven.

5. Drying of microscopic slides under incandescent bulb.

6. Olympus CX31 microscope with drawing tube and digital camera.

3.3. Part II- Breeding Biology, Feeding Biology and Mass-Rearing Protocols

3.3.1. Raising prey mite culture (*Suidasia nesbitti*)

The common storage pest mite, *Suidasia nesbitti*, was selected as the prey species and cultured in the laboratory to ensure a continuous supply of food for rearing the predatory mite *Cheyletus malaccensis*. The stock culture was initiated 45 to 60 days in advance to allow sufficient prey buildup before being offered to the predator. The initial population of *Suidasia nesbitti* was collected from infested stored products in warehouses using a direct extraction method, wherein individual mites were carefully picked with a wetted camel hair brush under the observation of Magnus stereozoom microscope. This approach ensured that no other acarine species were introduced into the culture. Mites of all developmental stages were selected to promote a sustainable colony. The overall process was laborious, requiring hours to isolate approximately 500 live specimens. Over a period of three weeks, around 20,000 mites were collected and inoculated into the rearing medium to establish a sufficiently large and stable prey population for the predator.

The rearing medium comprised a 1 kg mixture consisting of 600 g chickpea powder, 395 g wheat bran, and 5 g baker's yeast. Prior to use, the wheat bran and chickpea powder were sun-dried for two days to reduce fungal contamination. The culture was maintained in transparent plastic containers (24 cm × 16 cm × 6 cm), each fitted with eight ventilation openings (1 cm diameter) on the lid (Fig. 1 & 2 of Plate 3). These openings were covered with non-woven polypropylene fabric to prevent mite escape while ensuring adequate airflow. To sustain the culture, 3-4 replicate boxes were maintained in the laboratory. The prey population was monitored three times per week to assess colony health, growth, and substrate condition. If the substrate showed signs of deterioration, such as excessive faecal accumulation or mold growth, the mites were transferred to a fresh container with new medium to maintain optimal rearing conditions. This careful maintenance ensured a consistent and healthy prey population for the predatory mites.

3.3.2. Raising predator mite culture (*Cheyletus malaccensis*)

The predatory mite *Cheyletus malaccensis* was reared in transparent plastic containers (17 cm × 11 cm × 4.5 cm), each fitted with a lid containing eight ventilation openings (1 cm diameter) covered with non-woven polypropylene fabric. Each container was filled with 200 grams of a wheat-based substrate consisting of 80 g wheat bran, 60 g wheat flakes, and 60 g coarsely crushed wheat grains (Fig. 3 of Plate 3). This substrate provided a structural medium to support predator movement, oviposition, and foraging. Approximately 200 *Cheyletus malaccensis* individuals (mixed developmental stages) were introduced into each container to initiate the predator colonies. The initial predatory stock colony was established from mites extracted from infested stored products collected from storage warehouses. Individual *C. malaccensis* of all developmental stages were picked using a moistened camel-hair brush under the observation of Magnus stereozoom microscope**.** To sustain the predator populations, prey mites were added weekly at a rate of approximately 20,000 individuals per container. The prey quantity was estimated by subsampling 1 gram of the substrate, which allowed for extrapolation to the required number. To maintain a consistent culture volume and ensure continuous prey availability, an equivalent amount of fresh prey culture substrate was replenished weekly, directly compensating for the volume of substrate removed during the harvesting of prey mites. To prevent long-term deterioration of rearing conditions due to waste accumulation or prey depletion, the colonies were renewed every 30 days.

3.3.3. Preparation of 3D-printed Petri dishes for the rearing of *Cheyletus malaccensis*

Cheyletus malaccensis is a fast-moving predatory mite and confining them within the experimental setup without escaping is often very difficult. Conventional rearing systems for stored-product mites typically involve petri dish-like culture plates made of plaster of Paris and charcoal. However, these handmade vessels have inherent limitations as the porous nature of the materials provides hiding spots for mites, and containing them within the dish is often challenging. Preliminary trials revealed that cotton ring barriers, made by placing wetted cotton swabs around the periphery, were ineffective as mites either crossed the barrier or became trapped and died within the cotton fibers.

To overcome these challenges, a customized 3D-printed petri dish system was developed. The modified dish included a double-walled containment well, specifically designed to prevent mite escape. The inner wall measured 2 cm in diameter, the outer wall 3 cm in diameter, and both shared a height of 0.75 cm, creating a 0.5 cm wide interspace. This interspace, with a volume of approximately 2.2 mL, was filled with a mixture of 1.9 mL distilled water and 0.3 mL castor oil. The addition of castor oil minimized water evaporation while providing a highly effective physical barrier against mite escape.

Beyond the double-walled structure, the dish had an outer boundary corresponding to the standard dimensions of a regular petri dish, 9 cm in diameter and 1.5 cm in height. Two versions of the dish were 3D-printed:

1. A compact model containing only the double-walled well for space-efficient setups inside environmental chambers (Fig. 6 of Plate 3).
2. A full-size version including both the double-walled barrier and standard outer boundary for broader observational use (Fig. 7 of Plate 3).

Approximately 100 small-sized petri dishes were produced for partitioning eggs and individuals across multiple replicates, facilitating easy observation and avoiding clutter or overlapping individuals. The smaller design proved particularly advantageous when dealing with large populations and limited space.

The petri dish prototypes were initially created using Tinkercad (Autodesk Inc., USA), a user-friendly online 3D modelling tool, and further refined using Blender (Blender Foundation, Netherlands; Version 3.6, 2023), an open-source 3D creation suite. Final designs were exported in .obj file format and printed using a Prusa i3 MK3S+ 3D printer (Prusa Research, Czech Republic), with black PLA filament (Fig. 5 of Plate 3). Post-printing, excess material was carefully removed, and each unit was quality-checked for fluid retention and leakage.

The black coloration of the PLA material provided excellent contrast against the mite's pale body, enhancing visibility during observation. Moreover, the smooth, non-porous surface of the 3D-printed dishes eliminated the risk of mites hiding in structural cavities, a common issue with plaster-based plates.

3.3.4. Breeding and Feeding Biology of *Cheyletus malaccensis*

Developmental studies on *Cheyletus malaccensis* were conducted in laboratory environmental chambers with precisely regulated temperature and humidity conditions (Fig. 40 of Plate 3). Three temperature regimes (25 ± 1°C, 29 ± 1°C, and 33 ± 1°C) were cross-combined with three relative humidity levels (70 ± 5%, 80 ± 5%, and 90 ± 5%), creating nine distinct experimental treatments. To maintain a continuous 24-hour dark period, the chamber windows were covered with light-proof black film. *C. malaccensis* was reared on *S. nesbitti* as the prey source. Each treatment combination was replicated ten times, using newly emerged adult male and female *C. malaccensis* as the initial population. Males were taken out of the experimental setup immediately after the first egg was laid. The occurrence of female offspring in the F1 generation was considered confirmation of successful mating. Eggs were distributed into separate rearing petri dishes to facilitate management and prevent overcrowding or observational clutter.

Custom 3D-printed PLA Petri dish units served as rearing arenas, enabling individual monitoring while preventing escape and contamination (Fig. 1, Plate 3A). These units allowed clear visualization and facilitated daily observations across all developmental stages (egg to adult). Breeding biology was assessed through daily 19-hour observation sessions (8:30 AM to 3:30 AM), with hourly recordings of developmental transitions, behavioural changes, and stage durations. Chamber conditions were periodically verified to ensure parameter stability. Feeding biology was evaluated by offering different *C. malaccensis* life stages with varying *S. nesbitti* stages, and predation rates were recorded over 24-hour intervals.

3.3.5. Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 29.0 (IBM Corp., Armonk, NY, USA). A significance level of $p < 0.05$ was consistently applied for hypothesis testing. Two-way Analysis of Variance (ANOVA) for each dependent variable was done individually for all the key developmental parameters. The two main fixed factors in the experimental design were temperature and relative humidity, both treated as independent variables. These analyses allowed the assessment of main effects as well as potential interactions between temperature and humidity on each biological trait. Tukey's Honestly Significant Difference (HSD) test was employed as a post hoc procedure to compare group means while controlling for family-wise error, where statistically significant effects or interactions were identified.

Graphical summaries of the experimental outcomes were generated using R software (Version 4.3.2, R Core Team, 2023), with data first compiled and cleaned in Microsoft Excel (Microsoft Office 365, Microsoft Corp.). Statistical summaries and output results obtained from SPSS (used for inferential analyses) were subsequently imported into R for visualization. Bar plots and line charts were developed using the ggplot2 package (Wickham, 2016) to depict mean comparisons and developmental trends across different treatment conditions. Heat maps were generated using the geom_tile() function in ggplot2 to depict the number of prey individuals consumed by different predator stages, enabling a clear and comparative visualization of feeding patterns across prey stages. All plots incorporated appropriate axis scaling, standard error bars (±SE), and significance annotations to ensure alignment with the statistical outcomes. This dual-software approach, combining SPSS for statistical rigor and R for graphical clarity, enabled a coherent and visually effective presentation of complex biological patterns across treatments.

3.3.6. Life table parameters

Demographic calculations followed the frameworks of Birch (1948) and Southwood and Henderson (2000), using data from newly emerged adult females whose reproductive output and progeny development were monitored through to the next generation. Several key life history parameters were estimated to characterize the population growth dynamics. The net reproductive rate (R_0), which represents the average number of female offspring produced by a female over her lifetime, was calculated as the sum of the products of age-specific survival (l_x) and fecundity (m_x) across all age classes (i.e., $R_0 = \Sigma(l_x \cdot m_x)$). The intrinsic rate of increase (r_m), indicating the rate at which the population increases per individual per unit time under ideal conditions, was computed as the natural logarithm of R_0 divided by the mean generation time T (i.e., $r_m = \ln(R_0) / T$). The mean generation time (T), which reflects the average time between the birth of an individual and the birth of its offspring, was derived by dividing the sum of the products of l_x, m_x, and age (x) by the sum of $l_x \cdot m_x$ (i.e., $T = \Sigma(l_x \cdot m_x \cdot x) / \Sigma(l_x \cdot m_x)$). From the intrinsic rate, the finite rate of increase (λ), or the daily multiplication factor of the population, was calculated as the exponential of r_m (i.e., $\lambda = e^{rm}$). Lastly, the doubling time (DT), which estimates the time required for the population to double in size, was computed by dividing the natural logarithm of 2 by r_m (i.e., $DT = \ln(2) / r_m$). In all formulas, x denotes the age class in days, l_x is the probability of survival to age x, and m_x is the mean number of female offspring produced at age x. These parameters were computed in Microsoft Excel (Microsoft Office 365) using customized life table spreadsheets.

3.4 Mass rearing of the potential predatory mite *Cheyletus malaccensis* in laboratory

The predatory mite *Cheyletus malaccensis* was mass-reared using *Suidasia nesbitti* as prey in transparent plastic containers (17 × 11 × 4.5 cm) equipped with eight 1 cm diameter ventilation holes in the lid (four per side) covered with non-woven polypropylene cloth to allow airflow while preventing mite escape. Container edges were sealed with transparent cellophane tape for added security. Cultures were maintained in environmental chambers at 29 ± 1 °C, 80 ± 5% RH, and complete darkness to provide optimal rearing conditions.

3.4.1. Prey mite (*Suidasia nesbitti*) colony establishment

A mass culture of *Suidasia nesbitti* was initiated 15 days before predator rearing to ensure a steady prey supply. The colony began with 50,000 mixed-stage individuals sourced from a pre-existing culture, originally founded from 500 mites collected from infested stored products using a wetted camel hair brush under a stereozoom microscope to avoid contamination. Mites were reared in 1 kg of culture medium, reaching sufficient numbers by the F3 generation within 45 days. Subcultures were maintained separately for continuous production. For mass rearing, a 200 g substrate of chickpea powder (60%), wheat bran (39.5%), and baker's yeast (0.5%) was used, with wheat bran sun-dried for two days to remove residues and fungal growth, then conditioned for three days under rearing conditions. Multiple synchronized containers were maintained to meet predator demand (Fig. 2 of Plate 3).

3.4.2. Predator mite (*Cheyletus malaccensis*) rearing methodology

For *Cheyletus malaccensis* rearing, each of six containers was filled with 200 g of a wheat-based substrate comprising wheat flakes (30%), wheat bran (40%), and moderately crushed wheat grains (30%) (Fig. 3 of Plate 3). This substrate was designed to optimize habitat structure rather than serve as food, thereby enhancing predator mobility, oviposition, and foraging. While *S. nesbitti* preferred powdered substrates, *C. malaccensis* showed greater abundance in wheat-based systems, likely due to favorable structural or microhabitat conditions. Colonies were initiated with 400 mixed-stage predators. To sustain populations, 50,000–60,000 prey mites were added weekly, based on subsampling prey cultures (1 g contained approximately 2,500–3,000 mites). This required harvesting 20 g of prey-infested substrate weekly, with an equal amount of fresh prey medium replenished to maintain substrate stability, prey density, and minimal disturbance.

3.4.3. Predator population assessment

After 30 days, three randomly selected rearing units were processed using Berlese–Tullgren funnels for 72 h to extract mites from 200 g of substrate into 50 mL vials containing 70% ethanol. The suspension from each unit was homogenized and split into ten 5 mL aliquots; from each, a 1 mL subsample was examined under a stereomicroscope, counted, and extrapolated to the total 50 mL volume (×50) to estimate mite numbers per container, assuming uniform distribution. The remaining three units were processed after 60 days using the same method, enabling comparative analysis of population growth over time.

PLATE 3

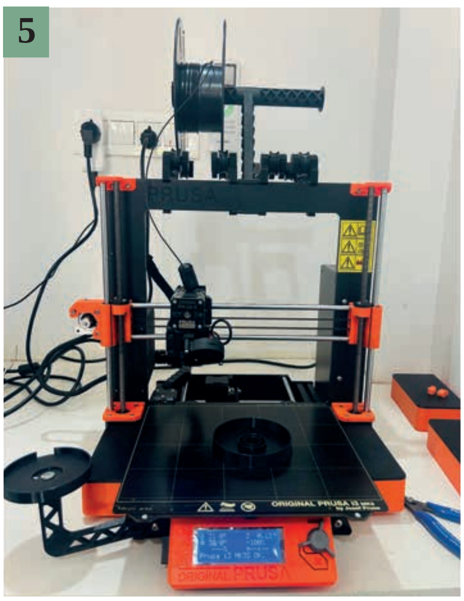
Figure 1-6. Materials and Methods

1. Plastic rearing containers showing ventilation holes.

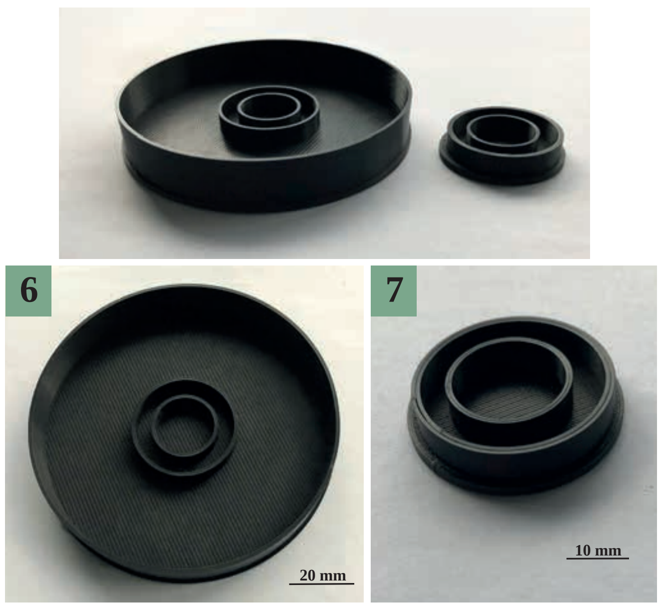
2. Prey mite stock culture container with culture medium

3. Predatory mite stock culture container with culture medium (same used for mass rearing)

4. Environmental chamber



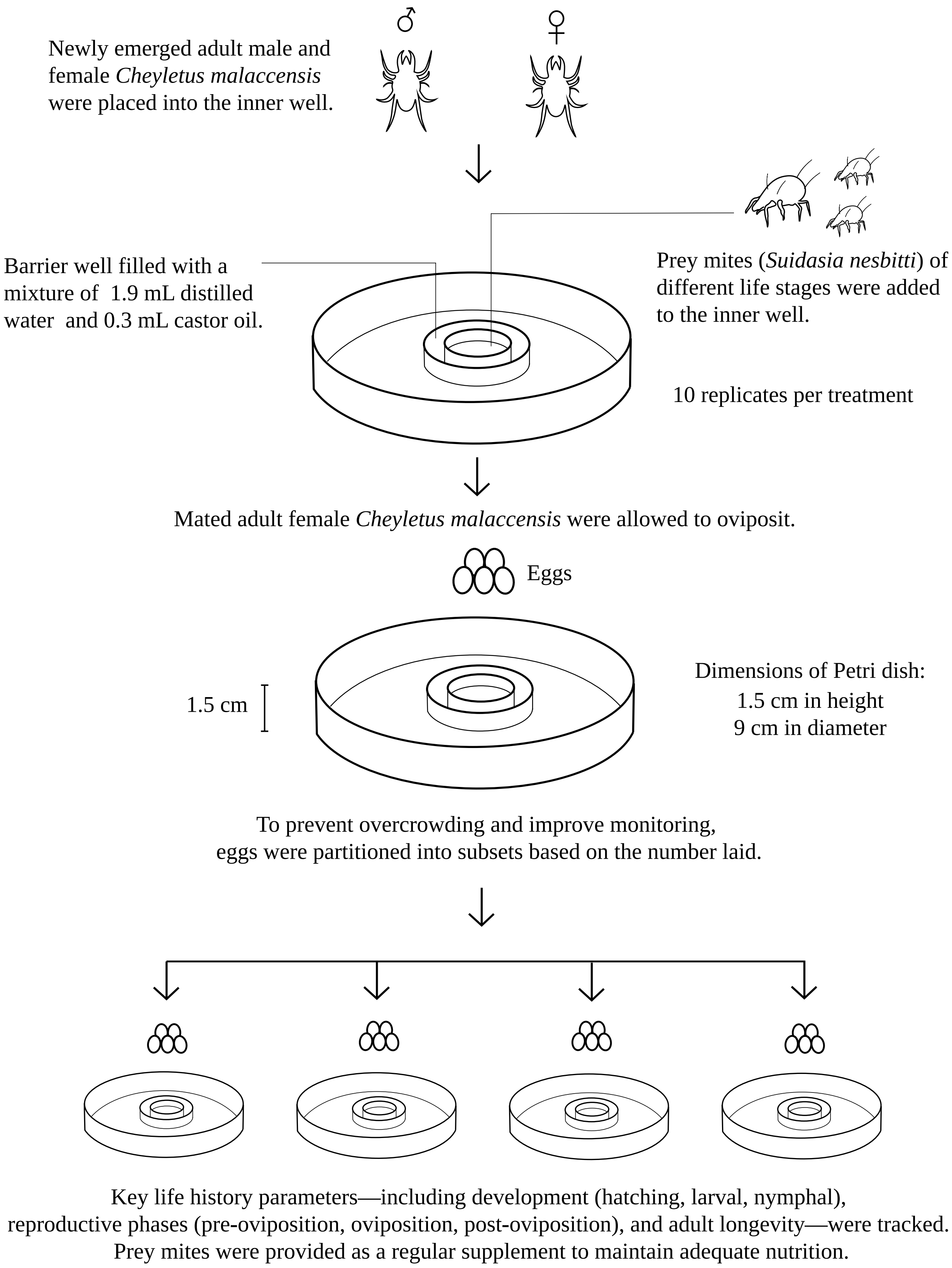
5. 3D printing of rearing Petri dish.



6. Regular-sized and 7.compact versions of 3D-printed rearing Petri dishes.

PLATE 3A

Figure 1. Schematic representation of the 3D-printed Petri dish rearing system



CHAPTER IV

RESULTS

4. RESULTS

4.1 Part I- Survey, taxonomy and identification

4.1.1. Results on collection and identification

During the study, 61 different storage facilities across six districts of North Kerala were surveyed, and 63 edible stored products were sampled to explore the diverse predatory mite fauna. The results revealed a total of 28 predatory species, classified within 19 genera, 13 families, and two extensive orders *viz*., Trombidiformes and Mesostigmata, belonging to the superorders Acariformes and Parasitiformes, respectively (Table 2 & 3). The order Trombidiformes within the superorder Acariformes comprised eight families, while the order Mesostigmata included in the superorder Parasitiformes encompassed five families. The obtained list of families, genera, and species is provided in Table 3.

Within this diversity, the mesostigmatid family Laelapidae exhibited a comparatively higher generic richness, constituting 15% of the total genera obtained from the survey. This family is represented by 3 genera, *viz*., *Androlaelaps*, *Euandrolaelaps,* and *Stratiolaelaps* and a total of four species from these genera were recorded. The species, *Stratiolaelaps scimitus* and *Euandrolaelaps karawaiewi* constituted first reports for India. Despite their generic diversity, the number of specimens obtained for each genus was relatively low, not exceeding six.

In contrast, the family Cheyletidae showed the maximum species diversity with five species identified across two genera, constituting 17% of all species obtained from the study. Among the recorded Cheyletid genera, *Acaropsella* was a new genus record for India, and a novel species belonging to this family *viz*., *Acaropsella strioreticulata*, was described from stored wheat semolina. This species exhibited a rare occurrence, with only five specimens recorded, and was not found from any other locations apart from the originally collected location (Kozhikode). The second genus of the family Cheyletidae, *Cheyletus*, was the most prevalent genus. Among this genus, *Cheyletus malaccensis* was found to be a robust, ubiquitous and most dominant species with high abundance. This species was prevalent across a significant number of surveyed storage facilities and was recorded in 52 out of 61 locations. Furthermore, *C. malaccensis* occurred in approximately 84% of the sampled stored products

(53 out of 63 types). A total of over 500 specimens of this species were collected from North Kerala.

In addition to *C. malaccensis*, the following species were identified within the genus *Cheyletus*: *C. eruditus*, *C. trouessarti*, and *C. carnifex*. The relative abundances of these *Cheyletus* species (excluding *C. malaccensis*) were 48%, 44%, and 7.4%, respectively.

The family Blattisociidae within the superfamily Ascoidea was represented by four species across two genera. Three species were identified in the genus *Blattisocius*, namely: *Blattisocius dentriticus*, *B. keegani*, and *B. tarsalis*. The genus *Hoploseius*, which also belongs to this family, encompassed a single species, *H. andamensis*. The occurrence of *H. andamensis* constituted the first documented record in stored products, expanding the known global habitat range for this species. Prior to this study, *H. andamensis* was known only from its original discovery location in the Andaman Islands. Following this, no reports have been documented to date. Hence, the present study documents its occurrence in mainland India for the first time. *Blattisocius keegani* was the second most abundant species overall, following *Cheyletus malaccensis*, with 24 specimens collected from 19 storage facility locations. Based on the number of specimens obtained during the survey, the relative abundances of Blattisociid mites were: *B. keegani* (55%) > *B. tarsalis* (20%) > *B. dentriticus* (16%) > *H. andamanensis* (6.9%).

The family Melicharidae, belonging to superfamily Ascoidea, was represented by two species within the genus *Proctolaelaps* (*P. pygmaeus* and *P. bickleyi*). The superfamily Sejoidea was represented by a single family, Sejidae. Within this family, the genus *Sejus* was identified with a single species, *Sejus carolinensis*, which was previously unrecorded in India and constituted a novel occurrence in stored products. The family Phytoseiidae comprised a single genus (*Amblyseius*) and species (*Amblyseius indirae*) obtained from stored pepper. Phytoseiid mites are rarely found in stored product environments, and *A. indirae* represents a newly recorded species within this habitat.

Superfamily Bdelloidea included the families Bdellidae and Cunaxidae. The family Bdellidae comprised the genera *Bdella* and *Spinibdella*. The species *viz*., *Bdella distincta*, *Spinibdella tabarii*, and *Spinibdella ampulla* were collected. Among which, *Spinibdella tabarii* and *Spinibdella ampulla* found to be new reports to India. Cunaxidae included the genera *Cunaxa* and *Scutopalus*. The species *Scutopalus pradhani* was redescribed due to insufficient morphological details and inadequate illustrations in its original publication. Furthermore, present study documents the first occurrence of genus *Scutopalus* in Kerala.

Superfamily Raphignathoidea exhibited the highest family diversity, encompassing Calligonellidae, Raphignathidae, and Stigmaeidae. The species *Paraneognathus wangae* belonging to family Calligonellidae and *Raphignathus neocardinalis* were reported for the first time from India. The family Stigmaeidae comprised only the genus *Storchia*, which included the single species *Storchia pacifica*. This species was also not previously known to occur in India. Thus, it constitutes a new genus and species record for India.

Superfamily Erythraeoidea comprised two families. Within the family Smarididae, the new species *Fessonia indica* was identified and described; furthermore, the genus *Fessonia* was previously unrecorded in India. The genus *Balaustium* (family Erythraeidae) was confined to one species, namely *Balaustium murorum*, which was not known to occur in India till date, thus constituted a new genus and species record for the country.

Among the stored products, boiled rice inhabited the highest number of predatory mite species (11), followed by raw rice (10) and wheat (7) (Table 1). The market warehouse located in Kozhikode district exhibited the greatest species richness (5 species). *Cheyletus malaccensis* and *Blattisocius keegani* were the most prevalent species in Food Corporation of India (FCI) warehouses (Table 2). This study documents the occurrence of 5 genera and 11 species that represent new reports (previously unrecorded) for the Indian predatory acarine fauna. This study also includes the two newly described species, *Acaropsella strioreticulata* and *Fessonia indica*. These findings contribute substantially to the understanding of predatory mite diversity in stored product ecosystems in North Kerala.

Definitive conclusions regarding geographic variation and stored product specificity for predatory mites were excluded due to the limited distribution of many species. several species were recorded from single locations which suggesting a low occurrence rate in stored products.

A total of 15 non-predatory mite species, comprising pest mites and fungal feeders, were recorded during the study. As the present study primarily focused on predatory mites, these non-target species were excluded from further analysis. The identified non-predatory mite species were:

1. *Acarus farris* (Oudemans, 1905)
2. *Acarus gracilis* Hughes, 1957
3. *Acarus siro* Linnaeus, 1758
4. *Aleuroglyphus ovatus* (Trouessart, 1897)

5. *Caloglyphus berlesei* (Michael, 1903)
6. *Glycyphagus destructor* (Schrank, 1781)
7. *Leiodinychus krameri* (G. & R. Canestrini, 1882)
8. *Rhizoglyphus robini* Claparède, 1869
9. *Suidasia nesbitti* Hughes, 1948
10. *Suidasia pontifica* Oudemans, 1905
11. *Trematura jacksoni* Oudemans, 1915
12. *Tropilichus aframericanus* Fain, 1968
13. *Tyroborus lini* Oudemans, 1924
14. *Tyrophagus longior* (Trouessart, 1897)
15. *Tyrophagus putrescentiae* (Schrank, 1781)

TABLE 2. Details of storage facilities surveyed and identified predatory mite species.

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
1.	04/12/2018	Kozhikode (Town) 11° 14' 56.4" N, 75° 46' 38.0" E	Market -Warehouse	Foxtail millet, Finger millet Fenugreek, Wheat, Mustard, Dried Chilly, Black gram, Green gram, Broken rice, Cumin seeds, Lentils, Arrowroot powder, Coriander	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Stratiolaelaps scimitus*
					4. *Storchia pacifica*
					5. *Cunaxa capreolus*
2.	12/12/2018	Kozhikode (Chelannur) 11° 22' 03.1" N, 75° 47' 39.5" E	Household	Soya bean, Wheat semolina, Corn semolina, Dried ginger	1. *Cheyletus malaccensis*
					2. Acaropsella strioreticulata
3.	23/01/2019	Kozhikode (West Hill) 11° 17' 14.0" N, 75° 45' 56.0" E	Food Corporation of India- Warehouse	Boiled rice, Raw rice, Wheat	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
4.	24/01/2019	Kozhikode (West Hill) 11° 17' 0" N, 75° 45' 43" E	Central warehousing corporation- Warehouse	Green pea, Lentils, Green gram, Raw rice, Basmati rice, Boiled rice	1. *Cheyletus malaccensis*
					2. *Cheyletus eruditus*
					3. *Blattisocius dentriticus*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
5.	24/01/2019	Kozhikode (Beach Road) 11° 16' 12.05" N, 75° 46' 03.4" E	Supplyco Sub Depot-warehouse	Wheat, Boiled rice, Raw rice, Coriander, Chick pea, Lentils, Finger millet	1. *Cheyletus malaccensis*
6.	12/02/2019	Kozhikode (Thamarassery-Vavad) 11° 23' 26" N, 75° 55' 18" E	Supplyco Depot-Warehouse	Wheat, Boiled rice, Raw rice, Coriander, Chick pea, Lentils, Finger millet, Green pea, Cumin seeds, Mustard, Dried chilly	1. *Cheyletus malaccensis*
					2. *Cheyletus eruditus*
					3. *Blattisocius keegani*
					4. *Proctolaelaps pygmaeus*
7.	12/02/2019	Kozhikode (Thamarassery-Paalakkutty) 11°22'16.2"N 75°54'33.4"E	Supplyco Depot-Warehouse	Wheat, Boiled rice, Raw rice, Coriander, chick pea, Lentils, Finger millet	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
8.	11/03/2019	Kozhikode 11° 17' 37.8" N, 75° 48' 15.6" E	Grocery Store	Dried Ginger, Green pea, Raw rice	1. *Cheyletus malaccensis*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
9.	03/04/2019	Wayanad (Bathery) 11° 39' 13.51" N, 76° 15' 28.07" E	Supplyco PDS depot	Pepper, Lentils, Chick pea, Cow pea, Turmeric, Raw rice, Boiled rice, Mustard, Cumin, Jaggery	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Paraneognathus wangae*
10.	16/04/2019	Wayanad (Mananthavady) 11° 45' 7" N, 76° 0' 33" E	Spice store	Bamboo rice, Pepper, Cardamom, Dried ginger, Cinnamon, Coffee beans	1. *Cheyletus malaccensis*
					2. *Amblyseius indirae*
					3. *Blattisocius tarsalis*
11.	16/04/2019	Wayanad (Meppadi) 11° 33' 24.5" N, 76° 07' 53.23" E	Spice store	Dried ginger, Cardamom, Cashew nuts, Pepper, Asparagus	1. *Cheyletus malaccensis*
					2. *Blattisocius tarsalis*
					3. *Paraneognathus wangae*
12.	09/05/2019	Kasargod (Nileshwar) 12° 15' 27.84" N, 75° 08' 05.60" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Fessonia indica*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
13.	31/05/2019	Kannur (Cherupuzha) 12° 16' 29.58"N, 75° 21' 51.39" E	Supplyco supermarket	Chick pea, Green Gram, Boiled rice	1. *Cheyletus malaccensis* 2. *Euandrolaelaps karawaiewi*
14.	22/08/2019	Kasargod (Thrikaripur) 12° 8' 40" N, 75° 10' 15" E	Household	Chick pea, Cow pea, Wheat, Raisins	1. *Cheyletus malaccensis* 2. *Proctolaelaps pygmaeus*
15.	27/09/2019	Kozhikode (Town) 11° 14' 59" N, 75° 46' 36" E	Market-Grocery store	Raw rice, Boiled rice, Mustard, Millet, Cumin, Fennel seeds.	1. *Cheyletus malaccensis* 2. *Cheyletus eruditus* 3. *Proctolaelaps bickleyi*
16.	14/10/2019	Kozhikode (Chethukadavu) 11° 18' 46.5" N, 75° 54' 8.9" E	Household	Chick pea, lentils, Green pea, Boiled rice	1. *Cheyletus malaccensis* 3. *Cheyletus carnifex* 3. *Stratiolaelaps scimitus*
17.	10/02/2020	Kozhikode (Atholi) 11° 22' 7" N, 75° 45' 9" E	Household	Black Gram, Dried prawns, Dried sole fish	1. *Cheyletus malaccensis* 2. *Cheyletus eruditus*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
18.	12/02/2020	Kannur (Dharmashala) 11° 58' 59" N, 75° 22' 36" E	Central warehousing corporation- Warehouse	Boiled rice, raw rice, wheat	1. *Cheyletus malaccensis*
					2. *Spinibdella tabarii*
					3. *Stratiolaelaps scimitus*
19.	18/02/2020	Kozhikode (Thikkodi) 11° 29' 40" N, 75° 37' 34" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, wheat	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Proctolaelaps pygmaeus*
20.	19/02/2020	Kozhikode (West Hill) 11° 17' 14" N, 75° 45' 56" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, wheat	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
21.	24/02/2020	Wayanad (Kalpetta) 11° 36' 53" N, 76° 4' 25" E	State Warehousing Corporation- Warehouse	Coffee bean with pod, Coffee bean without pod, Pepper	1. *Cheyletus malaccensis*
					2. *Amblyseius indirae*
					3. *Cunaxa capreolus*
22.	24/02/2020	Wayanad (Kalpetta) 11°37'36.2"N 76°04'15.3"E	Supplyco Depot- Warehouse	Green pea, green gram, lentil, Dried chili, Chick pea, cow pea, Black gram, Boiled rice, raw rice, Cumin seeds	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Proctolaelaps bickleyi*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
23.	24/02/2020	Wayanad (Meeanangadi) 11°39'18.6"N 76°09'22.2"E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat	1. *Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
					3. *Blattisocius keegani*
24.	27/05/2020	Kozhikode (Thalakkulathur) 11° 22' 07.25" N, 75° 45' 12.74" E	Household	Boiled rice, Dried edible mushroom	1. *Cheyletus malaccensis*
25.	30/08/2020	Kasargod (Kanhagad) 12°17'20.1" N 75°08'05.7" E	Household	Wheat semolina, Raisins, Peanuts, Cashew nuts, Rice flakes	1. *Cheyletus malaccensis*
					2. *Stratiolaelaps scimitus*
26.	30/08/2020	Kasargod 12° 30' 10" N, 74° 59' 20" E	Supplyco district depot	Lentils, Green pea, Green gram, Mustard, Chilly, Raw rice, Boiled rice, Chick pea	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Cunaxa capreolus*
27.	10/10/2020	Kasargod 12° 30' 11" N, 74° 59' 20" E	State warehousing Corporation-Warehouse	Pepper, Basmati rice	1. *Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
					3. *Bdella distincta*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
28.	10/10/2020	Kasargod (Hosdurg) 12° 38' 34.82" N, 74° 55' 35.24" E	Dry fruits store	Dried kiwi, Dates, Walnut, Almond, Cashew nuts.	1. *Cheyletus malaccensis* 2. *Sejus carolinensis*
29.	07/11/2020	Kasargod (Manjeshwar) 12° 43' 30.08" N, 74° 53' 08.05" E	Supplyco store	Raw rice, Boiled rice, Green gram, Dried chili, Mustard, Chick pea,	1. *Cheyletus malaccensis* 2. *Cheyletus eruditus* 3. *Raphignathus neocardinalis*
30.	07/11/2020	Kasargod (Kadumeni) 12°17'25.4"N 75°20'41.9"E	Household	Dried pepper, cashew nuts, Cardamom, Coco beans, Dried turmeric root, Cinnamon, Clove	1. *Cheyletus malaccensis* 2. *Bdella distincta*
31.	09/12/2020	Kannur (Dharmashala) 11° 58' 59" N, 75° 22' 36" E	Supplyco PDS depot	Raw rice, Boiled rice, Green pea, Green Gram,	1. *Cheyletus malaccensis* 2. *Spinibdella ampulla*
32.	11/12/2020	Kannur (Payyannur) 12° 05' 02.52" N, 75° 11' 58.56" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat	1. *Cheyletus malaccensis* 2. *Blattisocius keegani* 3. *Blattisocius dentriticus*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
33.	15/12/2020	Kasargod (Kanhagad) 12° 18' 36" N, 75° 5' 30" E	State warehousing Corporation- Warehouse	Raw cashew nuts, Coffee beans, Basmati rice, Green Gram.	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
34.	15/12/2020	Kasargod (Kanhagad) 12° 18' 35" N, 75° 5' 29" E	Supplyco taluk depot	Lentils, Green pea, Green gram, Mustard, Chilly, Raw rice, Boiled rice, Chick pea	1.*Cheyletus malaccensis*
					2. *Blattisocius dentriticus*
					3. *Cunaxa setirostris*
35.	15/12/2020	Kannur (Payyannur) 12° 06' 34.36" N, 75° 13' 07.43" E	Grocery store	Sesame, Cumin seeds, Rice flakes	1.*Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
36.	18/12/2020	Kannur (Thalipparamba) 12° 02' 28.34" N, 75° 21' 21.52" E	Supplyco Depot- Warehouse	Wheat, rice, mustard, Dried chili, Lentils, Green pea, Coriander, Finger millet	1. *Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
					3. *Blattisocius keegani*
					4. *Proctolaelaps bickleyi*
37.	05/01/2021	Malappuram (Kuttippuram) 10° 50' 42.00" N, 76° 02' 04.76" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat	1.*Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Blattisocius tarsalis*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
38.	16/02/2021 23/07/2022	Malappuram (Angadippuram) 10°58'55.4"N 76°12'34.3"E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat	1. *Cheyletus malaccensis* 2. *Blattisocius keegani*
39.	16/02/2021 23/07/2022	Malappuram (Angadippuram) 10° 58' 44.54" N, 76° 12' 27.14" E	Supplyco Depot	Green pea, Green gram, Lentils, Dried chili, Chick pea, Cow pea, Black gram, Boiled rice, Raw rice, Cumin seeds, Sugar	1.*Cheyletus malaccensis* 2. *Cheyletus eruditus* 3. *Scutopalus pradhani*
40.	23/04/2021	Malappuram (Manjeri) 11° 06' 35.83" N, 76° 07' 15.03" E	Supermarket	Pepper, Turmeric tubers, Dates, Black cumin seeds, Broken Brown rice.	1. *Cheyletus malaccensis* 2. *Blattisocius tarsalis* 3. *Cunaxa capreolus*
41.	23/04/2021	Malappuram (Manjeri) 11° 08' 04.16" N, 76° 06' 51.41" E	State warehousing Corporation-Warehouse	Raw rice, Boiled rice, Wheat, Lentils	1. *Cheyletus malaccensis* 2. *Proctolaelaps pygmaeus* 3. *Cunaxa capreolus*
42.	23/04/2021	Malappuram (Nilambur) 11° 16' 27" N, 76° 14' 6" E	Household	Dried oyster mushroom, Pearl millet, Finger millet	1. *Cheyletus malaccensis* 2. *Hoploseius andamanensis*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
43.	23/04/2021	Malappuram (Makkaraparamba) 11° 01' 00.20" N, 76° 07' 26.15" E	Household	Pistachio, Black Gram, Fenugreek, Dried black lemon	1. *Cheyletus malaccensis*
					2. *Proctolaelaps bickleyi*
44.	10/06/2021	Malappuram (Parappanangadi) 11° 03' 03.25" N, 75° 51' 24.21" E	Warehouse (Private)	Wheat flour, Wheat semolina	1. *Cheyletus malaccensis*
					2. *Blattisocius tarsalis*
45.	10/06/2021	Malappuram (Tirur) 10° 54' 55.89" N, 75° 55' 21.21" E	Grocery store	Fenugreek, Cumin seeds, Black gram, Mustard, Boiled rice, Lentils	1. *Cheyletus malaccensis*
					2. *Euandrolaelaps sardous*
46.	10/06/2021	Malappuram (Thanur) 10° 58' 34.21" N, 75° 52' 43.29" E	Supplyco Supermarket	Green Gram, Macaroni, Dried chili, Chick pea	1. *Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
47.	23/07/2021	Palakkad (Vadakkanthara) 10° 46' 25.88" N, 76° 38' 53.55" E	Supplyco supermarket	Brown Rice, Raw rice, Boiled rice, Lentils, Green gram	1. *Cheyletus malaccensis*
					2. *Cheyletus eruditus*
48.	23/07/2021	Palakkad (Puthuppariyaram) 10° 48' 28.63" N, 76° 37' 44.74" E	Food Corporation of India- Warehouse	Raw rice, Boiled rice, Wheat, Fortified rice.	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Blattisocius tarsalis*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
49.	23/07/2021	Palakkad (Kalvakulam-Mankavu) 10° 46' 25.51" N, 76° 40' 02.66" E	Supplyco Taluk depot	Lentils, Green gram, Raw rice, Boiled rice, Chick pea, Cumin, Fenugreek, Mustard, Wheat Semolina, Black gram, Chick pea, Lentils	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
					3. *Cunaxa setirostris*
50.	18/08/2021	Palakkad (Thayilpetti) 10° 45' 59.96" N, 76° 39' 17.02" E	State warehousing Corporation-Warehouse	Basmati rice, Green gram, Chick pea, Raw rice, Boiled rice	1. *Cheyletus malaccensis*
					2. *Androlaelaps casalis*
					3. *Blattisocius dentriticus*
51.	18/08/2021	Palakkad (Sultanpet) 10° 46' 15.40" N, 76° 39' 30.41" E	Supermarket	Lentils, Green gram, Cashew nuts, Peanuts, Rice powder	1. *Cheyletus malaccensis*
52.	25/10/2021	Palakkad (Melamuri) 10° 46' 25.25" N, 76° 38' 26.61" E	Supermarket	Raw rice, Sesame, Fenugreek, Nutmeg, Wheat semolina	1. *Cheyletus malaccensis*
					2. *Balaustium murorum*
53.	25/10/2021	Palakkad (Valiyangadi) 10° 46' 25.27" N, 76° 38' 46.83" E	Market-Grocery store	Black gram, Dried chili, Garlic, Raw rice, Basmati rice, Mustard, Broken rice, Dried fig	1.*Cheyletus malaccensis*
					2. *Androlaelaps casalis*
					2. *Cheyletus trouessarti*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
54.	22/11/2021	Palakkad (Pudussery-Kanjikode) 10° 47' 14.69" N, 76° 47' 07.67" E	Central Warehousing Corporation-Warehouse	Raw rice, Boiled rice, Basmati rice, Green pea, Green Gram, Lentils	1. *Cheyletus malaccensis*
					2. *Cunaxa capreolus*
55.	10/01/2022	Kozhikode (Velur) 11° 24' 15" N, 75° 45' 48" E	Oil mill	Copra	1. *Cheyletus malaccensis*
					2. *Cheyletus trouessarti*
56.	10/01/2022	Kozhikode (Kunnathara) 11° 24' 56" N, 75° 46' 6" E	Processing Unit	Copra	1. *Cheyletus malaccensis*
					2. *Cheyletus eruditus*
57.	10/01/2022	Kozhikode (Parambath) 11° 21' 18.43" N, 75° 45' 31.15" E	Supplyco supermarket	Chick pea, Horse gram, Boiled rice	1. *Cheyletus malaccensis*
58.	25/02/2022	Palakkad (Thekkenkunam) 10° 47' 23.08" N, 76° 41' 39.18" E	Flour mill	Raw-rice powder	1. *Cheyletus malaccensis*
					2. *Cunaxa setirostris*

Sl. No	Collection date	Location with geographical coordinates	Type of storage facility	Collected stored products	Collected predatory mite species
59.	25/02/2022	Malappuram (Manjeri) 11° 07' 14.93" N, 76° 07' 10.52" E	Supplyco supermarket	Chick pea, lentils, Raw rice, Dried chilly	1. *Cheyletus malaccensis*
					2. *Blattisocius keegani*
60.	18/03/2022	Kozhikode (Koliyotuthazham) 11° 22' 2" N, 75° 45' 28" E	Flour mill	Raw- rice powder Wheat flour	1. *Cheyletus malaccensis*
61	28/06/2024	Kozhikode (Quilandy) 11° 26.933' N, 75° 42.3' E	Household	Chickpea	1. *Cheyletus malaccensis*

TABLE 3. List of Collected Predatory Mite Species

Sl. No.	Family	Genus	Species
1.	Laelapidae	1. *Androlaelaps*	1.*Androlaelaps casalis*
		2. *Euandrolaelaps*	2. *Euandrolaelaps karawaiewi* 3. *Euandrolaelaps sardous*
		3. *Stratiolaelaps*	4. *Stratiolaelaps scimitus*
2.	Blattisocidae	4. *Blattisocius*	5. *Blattisocius dentriticus* *6. Blattisocius keegani* *7. Blattisocius tarsalis*
		5. *Hoploseius*	8. *Hoploseius andamanensis*
3.	Melicharidae	6. *Proctolaelaps*	9. *Proctolaelaps bickleyi* *10. Proctolaelaps pygmaeus*
4.	Phytoseiidae	7. *Amblyseius*	*11. Amblyseius indirae*
5.	Sejidae	8. *Sejus*	12. *Sejus carolinensis*
6.	Cheyletidae	9. *Acaropsella*	*13. Acaropsella strioreticulata*
		10. *Cheyletus*	14. *Cheyletus carnifex* 15. *Cheyletus eruditus* 16. *Cheyletus malaccensis* 17. *Cheyletus trouessarti*
7.	Bdellidae	11. *Bdella*	18. *Bdella distincta*
		12. *Spinibdella*	19. *Spinibdella ampulla* 20. *Spinibdella tabarii*
8.	Cunaxidae	13. *Cunaxa*	21. *Cunaxa capreolus* 22. *Cunaxa setirostris*
		14. *Scutopalus*	23. *Scutopalus pradhani*
9.	Erythraeidae	15. *Balaustium*	24. *Balaustium murorum*
10.	Smarididae	16. *Fessonia*	25. *Fessonia indica*
11.	Caligonellidae	17. *Paraneognathus*	26. *Paraneognathus wangae*
12.	Raphignathidae	18. *Raphignathus*	27. *Raphignathus neocardinalis*
13.	Stigmaeidae	19. *Storchia*	28. *Storchia pacificus*

4.2 Taxonomic studies and identification of specimens

Results of the identification of the slide-mounted specimens up to species level are presented in this section. Morphometric measurements, specimen imaging, and hand-drawn illustrations are detailed here (Plates 4–31). The results also revealed that 13 species of predatory mites were recorded for the first time in India, of which five were new genus-level records (Table 4). Microscopic slide images of all 28 species are provided in Plates 32–35.

4.2.1 Systematic Position

Class: Arachnida Cuvier, 1812

Subclass: Acari Leach, 1817

I. Superorder: Parasitiformes Reuter, 1909

Order: Mesostigmata G. Canestrini, 1891

Superfamily: Dermanyssoidea Kolenati, 1859.

I. Family: Laelapidae Berlese, 1892

a) Genus: *Androlaelaps* Berlese, 1905

Species: 1. *Androlaelaps casalis* (Berlese, 1887)

b) Genus: *Euandrolaelaps* Bregetova, 1977

Species: 2. *Euandrolaelaps karawaiewi* Berlese, 1904

3. *Euandrolaelaps sardous* Berlese, 1911

c) Genus: *Stratiolaelaps* Berlese, 1916

Species: 4. *Stratiolaelaps scimitus* Womersley, 1956

Superfamily: Ascoidea Voigts and Fauzago, 1877

II. Family: Blattisociidae Garman, 1948

d) Genus: *Blattisocius* Keegan, 1944

Species: 5. *Blattisocius dentriticus* Berlese, 1918

6. *Blattisocius keegani* Fox,1947

7. *Blattisocius tarsalis* Berlese, 1918

e) Genus: *Hoploseius* Berlese, 1914

Species: 8. *Hoploseius andamanensis* Bhattacharyya, 2002

III. Family: Melicharidae Hirschmann, 1962

f) Genus: *Proctolaelaps* Berlese, 1923

Species: 9. *Proctolaelaps bickleyi* Bram,1956

10. *Proctolaelaps pygmaeus* Müller, 1859

Superfamily: Phytoseioidea Berlese, 1916

IV. Family: Phytoseiidae Berlese, 1916

Sub family: Amblyseiinae Muma, 1961

g) Genus: *Amblyseius* Berlese, 1914

Species: 11. *Amblyseius indirae* Gupta, 1985

Superfamily: Sejoidea Berlese, 1885

V. Family: Sejidae Berlese, 1913

h) Genus: *Sejus* Koch, 1836

Species: 12. *Sejus carolinensis* Lekveishvili & Klompen, 2004

II. Superorder: Acariformes Zakhvatkin, 1952

Order: Trombidiformes Reuter, 1909

Superfamily: Cheyletoidea Leach, 1815

VI. Family: Cheyletidae Leach, 1815

i) Genus: *Acaropsella* Volgin, 1962

Species: 13. *Acaropsella strioreticulata* Martin & James, 2023

j) Genus: *Cheyletus* Latreille, 1796

Species: 14. *Cheyletus carnifex* Zachvatkin, 1935

15. *Cheyletus eruditus* Schrank, 1781

16. *Cheyletus malaccensis* Oudemans, 1903

17. *Cheyletus trouessarti* Oudemans, 1903

Superfamily: Bdelloidea Duges, 1834

VII. Family: Bdellidae Dugès, 1834

k) Genus: *Bdella* Latreille, 1795

Species: 18. *Bdella distincta* Baker and Balock, 1944

l) Genus: *Spinibdella* Thor, 1930

Species: 19. *Spinibdella ampulla* Wallace & Mahon, 1972

20. *Spinibdella tabarii* Paktinat-Saeej & Bagheri, 2015

VIII. Family: Cunaxidae Thor, 1902

m) Genus: *Cunaxa* Von Heyden, 1826

Species: 21. *Cunaxa capreolus* Berlese, 1918

22. *Cunaxa setirostris* Hermann, 1804

n) *Scutopalus* Den Heyer, 1979

Species: 23. *Scutopalus pradhani* Gupta & Gosh, 1980

Superfamily: Erythraeoidea Grandjean, 1947.

IX. Family: Erythraeidae Robineau-Desvoidy, 1828

o) Genus: *Balaustium* Von Heyden, 1826

Species: 24. *Balaustium murorum* Hermann, 1804

X. Family: Smarididae Kramer, 1877

p) Genus: *Fessonia* Von Heyden, 1826

Species: 25. *Fessonia indica* Martin and James, 2024

Superfamily: Raphignathoidea Kramer, 1877

XI. Family: Caligonellidae Grandjean, 1949

q) Genus: *Paraneognathus* Fan, 2000

Species: 26. *Paraneognathus wangae* Fan & Li, 1995

XII. Family: Raphignathidae Kramer, 1877

r) Genus: *Raphignathus* Dugés, 1834

Species: 27. *Raphignathus neocardinalis* Atyeo, 1963

XIII. Family: Stigmaeidae Oudemans, 1931

s) Genus: *Storchia* Oudemans, 1923

Species: 28. *Storchia pacificus* Summers, 1964

4.2.2. Morphological Terminology and Description of Species

4.2.2.1. Order Mesostigmata

Dorsal setae

j1-j6	Vertical setae (dorsocentral series on podonotal region)
J1-J5	Clunal setae (dorsocentral series on opisthonotal region)
Jx	Extra dorsocentral seta not assignable to J1-J5
z1-z6	Podonotal mediolateral setae
Z1-Z5	Opisthonotal mediolateral setae
s1-s6	Podonotal dorsolateral setae
S1-S5	Opisthonotal dorsolateral setae
Sx	Extra dorsolateral seta not assignable to S1-S5
r1-r6	Podonotal marginal setae
R1-R6	Opisthonotal marginal setae

Ventral setae

st1-st3	Sternal setae on sternal shield
st4	Metasternal setae
st5	Genital setae on genital shield (female)
JV1-JV5	Preanal setae on ventrianal shield
ZV1-ZV5	Preanal setae on ventrianal shield
JV5	Caudal seta
a1-a3	Circumanal (anal) setae
UR series	Posterior submarginal row of ventral setae
po / POS	Postanal unpaired seta

Shields and Sclerotized Regions

Podonotal shield	Anterior dorsal shield bearing j, z, s, r series
Opisthonotal shield	Posterior dorsal shield bearing J, Z, S, R series
Mesonotal shield	Transverse shield between podonotal and pygidial regions
Pygidial shield	Shield at terminal end of idiosoma
Sternal shield	Shield between coxae II–III bearing st1-st3
Metasternal platelets	Platelets bearing st4
Genital shield	Shield bearing st5 in females
Sternogenital shield	Male shield covering genital opening
Ventrianal shield	Composite ventral shield encompassing preanal and anal regions
Exopodal shields	Strap-like shields lateral to coxae
Endopodal shield	Narrow angular to subtriangular shield positioned around the bases of the coxae
presternal platelets	Sclerites anterior to sternal shield
epigynal shield	Shield covering female genital area

Gnathosoma and Chelicerae

pc / pcx	Palpcoxal setae (most basal on subcapitulum)
elcp	Elcophore (Supracoxal seta on palp)
pili dentilis	Sensory organ on cheliceral digit
tectum	Shelf-like projection on gnathosoma (also called epistome)

Leg and Palp Chaetotaxy

pd1-pd3	Postero-dorsal setae
pl1-pl2	Postero-lateral setae
pv1-pv3	Postero-ventral setae

av1-av3	Anterior ventral setae
al1-al2	Antero-lateral setae
apotele	Terminal claw-bearing leg segment
pulvillus	Pad-like structure between claws
Empodium	A single, pad-like or claw-like structure located between the tarsal claws, often bearing tenent hairs

4.2.2.2. Order Trombidiformes

Gnathosoma

Subcapitulum	Venter of the capitulum and the ventral faces of the fused palpcoxae
Hypostome	Anterior part of the subcapitulum
Hypognathum	Ventral gnathosoma bearing palps, chelicerae and subcapitular setae
m	Anteriormost subcapitular seta
n	Posterior subcapitular seta
ro1/ro2	Rostral setae (Internal/external pairs)

Palps

acc	Accessory claw (Slender, seta-like on palptibia)
ω	Solenidion (On palptarsus)
Eupath/ zeta (ζ)	Eupathidia (an optically active, hollow seta with a pore at its tip and found on the palptarsus or leg I tarsus. Functions as a chemoreceptor)

Dorsal idiosoma

Idiosoma	The main body, containing the opisthosoma and part of the prosoma
Proterosoma	The body anterior to the sejugal plane (suture); complementary to the hysterosoma vi/ve – Internal/External vertical setae
sci/sce	Internal/External scapular setae
pob	Postocular body (Absent in some taxa)

Trichobothria	Intricately modified seta positioned in a cup-like base
at	Anterior trichobothria
pt	Posterior trichobothria
Crista metopica	Narrow prodorsal sclerite bearing 1-2 pairs of trichobothria
Hysterosoma	Idiosoma behind the sejugal furrow between legs II-III
C	First segment of hysterosoma, comprising a row of setae *c*
D	Second segment of hysterosoma, comprising a row of setae *d*
E	Third segment of hysterosoma, comprising a row of setae *e*
F	Fourth segment of hysterosoma, comprising a row of setae *f*
H	Fifth segment of hysterosoma, comprising a row of setae *h*
PS	Sixth segment of hysterosoma, comprising a row of setae *ps*
Aspid	Aspidosoma
Opisthosoma	Posterior body division

Shields and Platelets

F	Intercalary shields (With setae *f1*/*f2*)
H	Suranal shield (With setae *h1*-*h3*) / Humeral shields (Bearing *c2*)

Dorsal setae

v1/ vi	Internal vertical seta on the prodorsum
v2/ ve	External vertical seta on the prodorsum
c1	First pair of setae in 1st series on hysterosoma
c2	Second pair of setae in 1st series on hysterosoma
d1	First pair of setae in 2nd series on hysterosoma
d2	Second pair of setae in 2nd series on hysterosoma
e1	First pair of setae in 3rd series on hysterosoma

e2	Second pair of setae in 3rd series on hysterosoma
f1	First pair of setae in 4th series on hysterosoma
f2	Second pair of setae in 4th series on hysterosoma
h1	First pair of setae in 5th series hysterosoma
h2	Second pair of setae in 5th series hysterosoma
h3	Third pair of setae in 5th series hysterosoma

Cupules /Lyrifissures

ia	Anterior pair of cupules on hysterosoma,
im	Middle pair of cupules on hysterosoma
ip	Posterior pair of cupules on hysterosoma
ih	Caudal pair of cupules on hysterosoma

Ventral Idiosomal setae

1a	First pair of setae associated with bases of legs I
1b	Second pair of setae associated with bases of legs I
1c	Third pair of setae associated with bases of legs I
2b	Second pair of setae associated with bases of legs II
2c	Third pair of setae associated with bases of legs II
3a	First pair of setae associated with bases of legs III
3b	Second pair of setae associated with bases of legs III
3c	Third pair of setae associated with bases of legs III
4a	First pair of setae associated with bases of legs IV
4b	Second pair of setae associated with bases of legs IV
4c	Third pair of setae associated with bases of legs IV
ag1	Anterior/ first pair of aggenital setae

ag2	Second pair of aggenital setae
ag3	Third pair of aggenital setae
ag4	Fourth pair of aggenital setae
ag5	Fifth pair of aggenital setae
g1	First pair of genital setae
g2	Second pair of aggenital setae
g3	Third pair of genital setae
ps1	First pair of pseudanal setae
ps2	Second pair of pseudanal setae
ps3	Third pair of pseudanal setae

Leg setae and solenidia

Empod	Empodium (Branching with 3 tenent hairs)
Solenidion	A hollow, optically inactive chemosensory seta on the legs
Iω	Solenidion on tarsus I
Iω1	Anterior solenidion on tarsus I in male
Iω2	Posterior solenidion on tarsus I in male
Iωp	Proximal solenidion on tarsus I in female
Iϕ	Solenidion on tibia
I Iϕ’	Anteriorly positioned solenidion on tibia I
Iϕ”	Posteriorly Positioned solenidion on tibia I
Iϕp	Proximal solenidion on tibia I
Iκ	Sensillum on genu I
asl	Attenuate solenidion
bsl	Blunt rod-like solenidion

spls Spine-like seta

sts Simple tactile seta

elcp Elcophore (Supracoxal seta on palp)

fam Famulus (ε), a hollow and optically active seta-like/ peg like structure positioned on tarsus I

4.2.3. Morphological Descriptions of Species

4.2.3.1. Family Laelapidae Canestrini, 1891

Gamasini Canestrini, 1885: 49.

Gamasidae Canestrini, 1891: 723; Banks, 1904: 1.

Iphiopsidae Kramer, 1886: 254; Vitzthum, 1929: 16; Baker and Wharton, 1952: 90; Farrier and Hennessey, 1993: 63.

Iphiopsinae Keegan, 1950: 511; Evans, 1955: 352; Vitzthum, 1942: 766.

Laelaptidae Canestrini, 1891: 722; Berlese, 1906: 86; Hughes, 1948: 129; Willmann, 1952a: 393; Bregetova, 1956: 70; Schweizer, 1961: 145.

Laelaptinae Radford, 1950a: 30; Baker and Wharton, 1952: 93; Evans, 1957: 230; Zumpt and Till, 1958: 263.

Laelapidae Domrow, 1963: 9; Evans and Till, 1966: 111; Krantz, 1978: 132; Zaher, 1986: 176; Casanueva, 1993: 23; Deng et al., 1993: 62; Farrier and Hennessey, 1993: 63; Moraes et al., 2022: 5, 125; Bandyopadhyay et al., 2023: 402.

Parasitidae Oudemans, 1902a: 49; Banks, 1915: 71; Vitzthum, 1931: 142.

Pseudoparasitidae Vitzthum, 1942: 757; Baker and Wharton, 1952: 74.

Neoparasitidae Vitzthum, 1942: 755; Baker and Wharton, 1952: 72; Evans, 1957: 220; Schweizer, 1961: 84.

Dermanyssidae Evans and Till, 1966: 109; Karg 1971: 157; Hughes, 1976: 286.

Hypoaspididae Karg, 1993: 132; 2000: 244; Faraji et al., 2008: 205; Karg and Schorlemmer, 2013: 196.

Hypoaspidinae Vitzthum, 1942: 762; Radford, 1950a: 12; Baker and Wharton, 1952: 91; Turk, 1953: 11; Zhang et al., 1963: 185.

Otopheidomenidae Treat, 1955: 556; Krantz and Khot, 1962: 535.

Diagnosis: Chelicera features chelate-dentate digits, typically comprises a bidentate movable digit in females. Male movable digit bear one tooth; basally feature a fused spermatodactyl on the external digit face, variable in length. Epistome with serrated or smooth margin. Palp tarsal claw bifurcated, sometimes trifurcated. Idiosoma typically features a holodorsal shield comprising approximately 39 pairs of setae, complemented with one to five unpaired setae in the *J* series. Slight to moderate dorsal hypotrichy or hypertrichy observed. Presternal area lightly sclerotised, displaying lineate reticulate pattern; occasionally differentiate into two distinct sclerites. Sternal shield generally intact, carrying *st*1-3; exhibits considerable variation across different genera, such as being shortened and widened or partially desclerotized, sometimes leaving *st*1 or *st*3 on unsclerotized integument or coalesce posterolaterally with the endopodal plates. Seta *st*4 and poroid *iv*3 positioned on unsclerotized integument. Linguiform epigynal shield, reaching posteriorly beyond coxae IV, usually bearing *st*5; shield overlaps the sternal shield posteromedially with a hyaline extension. Opisthogastric shield may be enlarged, remain free or coalesce with anal shield to form a hologastric shield bearing one or more pairs of opisthogastric setae. Anal shield typically small and variable in shape, ranging from inverted subtriangular to oblong. Peritrematal plate narrow, free or coalesced with dorsal shield anteriorly; free and tapering posteriorly. Pretarsi possess claws. Leg setation (holotrichous) consists of 13 setae on femur I, genu I and tibia I; 9 setae on genu III-IV; 8 setae on tibia III; 10 setae on tibia IV.

Leg chaetotaxy **Type genus: *Laelaps* Koch, 1836**

Key to the genera belonging to the family Laelapidae obtained from the present study

1. Dorsal shield setae spatulate-tricarinate; corniculi elongate, reaching palp femur tip; *h1* much longer than *h3*…………………………… Genus *Stratiolaelaps* Berlese,1916
- Dorsal shield setae not spatulate-tricarinate; corniculi not elongate, not reaching palp femur tip; *h1* slightly longer than or subequal to *h3*……………………………......... 2
2. Epigynal shield with a narrow constriction between coxae IV; fixed digit of chelicera with 3 large teeth and seven to nine small subsidiary teeth; pilus dentilis not hypertrophied……………………………...... Genus *Euandrolaelaps* Bregetova, 1977
- Epigynal shield without a distinct narrow constriction between coxae IV; fixed digit of chelicera with one to three reduced teeth (sometimes edentate); pilus dentilis hypertrophied…………………………….............. Genus *Androlaelaps* Berlese, 1903

Genus *Androlaelaps* Berlese, 1903

Laelaps (*Androlaelaps*) Berlese, 1903: 14; 1904: 432.

*Androlaelap*s Berlese, 1913a: 10; Vitzthum, 1942: 762; Radford, 1950a: 19; Zumpt and Patterson, 1951: 69; Bregetova, 1977a: 533; Keegan, 1956: 226, Evans, 1957: 230; Zhang et al., 1963: 186; Evans and Till, 1979: 200; Athias-Henriot, 1968: 237; Karg, 1971: 185; Hughes, 1976: 288; Radovsky, 1985: 454; Domrow, 1988: 825; 4; Karg 1993: 162; Gettinger and Gardner, 2015: 245; Vinarski and Vinarskaya, 2016: 232; Hajizadeh and Joharchi, 2018: 26; Nemati et al., 2021: 185; Moraes et al., 2022: 129.

Atricholaelaps Ewing, 1929: 186.

Cyclolaelaps Ewing, 1933: 5.

*Ischnolaelap*s Vitzthum, 1942: 769; Strandtmann and Wharton, 1958: 32.

Cavilaelaps Fonseca, 1936: 25.

Hypoaspis (*Androlaelaps*) Vitzthum, 1942: 762; Zumpt, 1950b: 299; Baker and Wharton, 1952: 94.

Zygolaelaps Tipton, 1957: 367; Tipton, 1960: 247.

Eschnolaelaps Zaher, 1986: 180.

***Diagnosis*:** Fixed digit of female chelicera bears 1-3 teeth, occasionally edentate; pilus dentilis usually hypertrophied or expanded; in the absence of these features, distinctly elongated. In males, fixed and movable cheliceral digit edentate without apical hook; fixed digit reduced, movable digit bears wide, elongated spermatodactyl; pilus dentilis positioned proximally. Dorsal idiosomal shield generally elliptical or oval in outline, bearing 39 pairs of setae of comparable length; typically comprises additional 2-3 setae in opisthodorsal *Z* series (occasionally absent, including *z3*). Dorsal setal length varies, ranging from very short to distinctly long forms, or only *Z5* elongated. Unsclerotized idiosomal integument densely setose. Epigynal shield pyriform or, rarely, linguiform in shape, demarcated and separated from anal shield, or positioned in close proximity; ornamented with 4 to 5 prominent transverse striae, bears *st5* and occasionally *ZV*1 or *JV*1, positioned near the border. Opisthogastric and lateral membranous integument generally equipped 5-15 lateral opisthodorsal (*R*) and posterior submarginal seta (*UR*) excluding *JV-ZV* setae, occasionally densely hypertrichous. In males, a moderate expansion observed in the opisthogastric area of holoventral or sternogenital shield. Leg II features stout anterior ventral setae on femur, genu, and tibia, in addition to stout subapical setae on tarsus. Genu IV bears 10 setae, including 2 postero-lateral setae (*pl*); tibia III possess 7 setae, occasionally with 2 *pl*. Genu III carries 8 setae, including 2 *pl*; tibia I rarely features 2 postero-ventral setae (*pv*) excluding 12 setae.

Type species: *Laelaps* (*Iphis*) *hermaphrodita* Berlese, 1887

Androlaelaps casalis (Berlese, 1887)

PLATE 4

Iphis casalis Berlese, 1887: 4; 1892: 41; Sheals, 1964: 15.

Laelaps casalis Berlese, 1892: 42.

Hypoaspis oculatus Oudemans, 1915: 183; Strandtmann and Wharton, 1958: 34; Till, 1963: 23; Karg, 1971: 187; 1993: 164.

Haemolaelaps oculatus Oudemans, 1929: 13; Sellnick, 1940: 28; Buitendijk, 1945: 299.

Haemolaelaps megaventralis Zumpt and Patterson, 1951: 70; Bregetova, 1952: 872; Meng et al., 2021: 4.

Hypoaspis freemani Hughes, 1948: 129.

Haemolaelaps casalis Allred and Beck, 1956: 40; Bregetova, 1956: 89; Strandtmann and Wharton, 1958: 34; Tipton, 1960: 242; Karg, 1965: 312; Domrow, 1988: 829; Xin et al., 2010: 2; Ma and Yin, 2011: 119; Nemati and Gwiazdowicz, 2016a: 44; Meng et al., 2021: 4.

Androlaelaps casalis Till, 1963: 23; Costa, 1966: 73; Wilson, 1967: 137; Athias-Henriot, 1968: 251; Treat, 1975: 64; Karg, 1971: 185; 1993: 272; Beron, 1974: 173; Prasad, 1974: 150; Bregetova, 1977a: 533; Whitaker, 1977: 195; Zaher, 1986: 181; Sklyar, 2001: 101; Marchenko, 2002: 45; Gwiazdowicz and Klemt, 2004: 14; Shaw, 2014: 290; Vinarski and Vinarskaya, 2016: 233; Hajizadeh and Joharchi, 2018: 26; Halliday et al., 2018: 49; Negm et al., 2018: 726; Nemati et al., 2018b: 133; Joharchi and Negm, 2020: 489; Moraes *et al*, 2022: 137

Androlaelaps casalis casalis Evans and Till, 1966: 152; Farrier and Hennessey, 1993: 64.

Androlaelaps (*Haemolaelaps*) *casalis* Barrera, 1979: 477; Bassols, 1981: 15; Light et al., 2020: 84.

Diagnosis

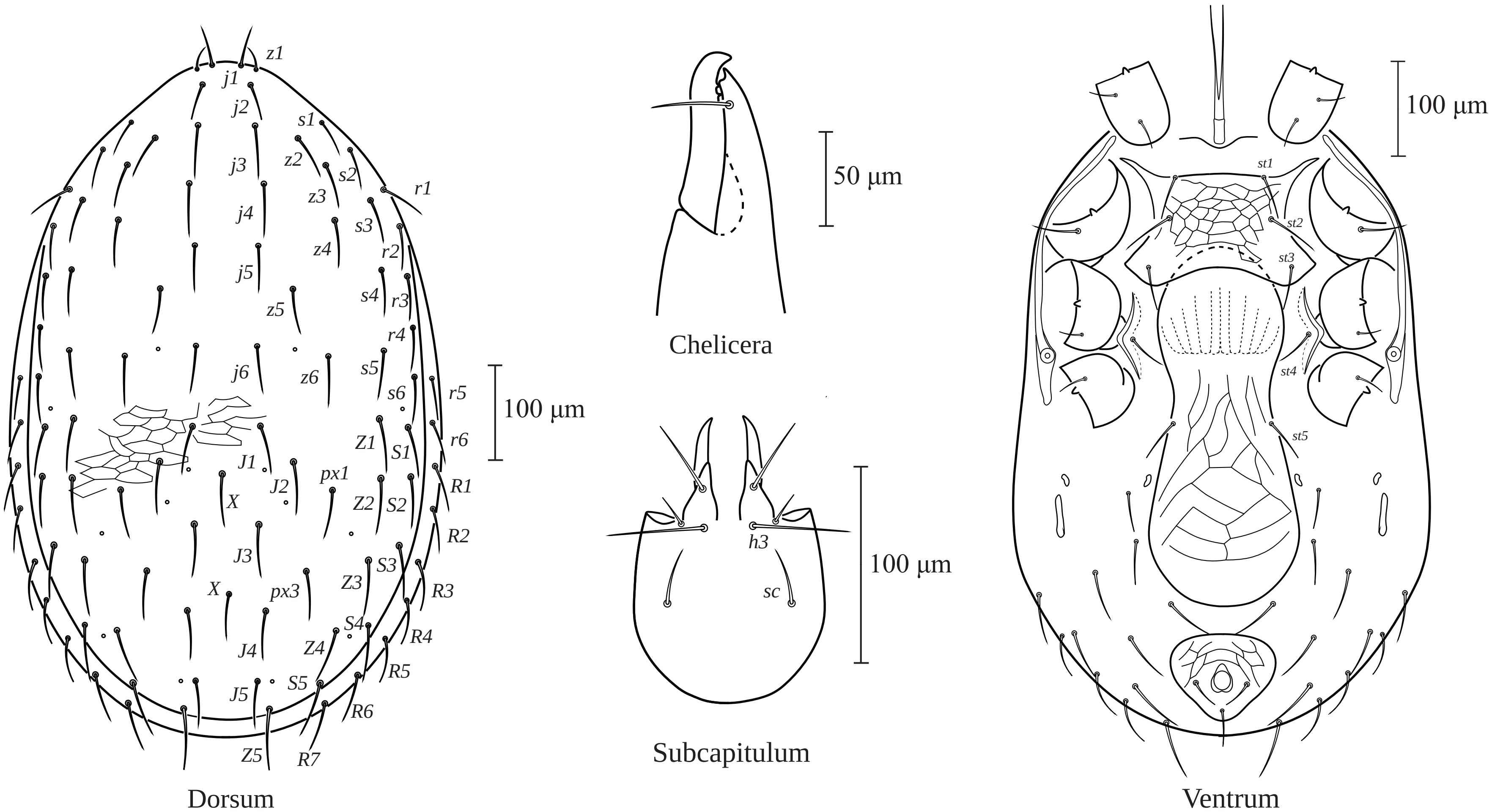
Female: Mean size of idiosoma: 654 x 450 µm. Deutosternum with 6 rows of 5 fine denticles each. Tectum hood-like, with well-sclerotized corniculi. Cheliceral fixed and movable digits each bear two diminutive teeth. Pilus dentilis long and slender, positioned on fixed digit. Dorsal shield oval, adorned with reticulations, bearing 39 pairs of setae, along with a variable number of unpaired accessory setae interspersed among the setal rows. Posterior setae elongated and barbed; opisthonotal seta *J5* 1.5 times as long as *Z5*. Sternal shield ornamented with reticulations. Genital shield also reticulated and expanded posteriorly; genital setae short. Metapodal plates elongated, 4 to 7 times longer than wide. Metapodal plates accompanied by smaller plates posterior to coxae IV. Peritrematal and exopodal plates remains distinct and non-confluent; anterior end of peritrematal plate not coalesced with dorsal shield. Anal shield subtriangular, reticulated, and as long as broad. Paranal setae arise approximately midway along the anus, subequal in length to the postanal seta. Tarsus II features three robust ventral and apical setae. Tarsus IV elongated, approximately six times longer than its proximal width.

Male: Not obtained.

Materials Examined:

- One female specimen from Palakkad (State Warehousing Corporation- Thayilpetti, 10° 45' 59.96" N, 76° 39' 17.02" E), collected from raw rice on 23 September 2022 by Neeraj Martin.
- Two female specimens from Palakkad (Valiyangadi, 10° 46' 25.27" N, 76° 38' 46.83" E), collected from stored basmati rice on 23 September 2022 by Neeraj Martin.

PLATE 4



Androlaelaps casalis **(Berlese, 1887), Adult female**

Genus *Euandrolaelaps* Bregetova, 1977

Hypoaspis (*Euandrolaelaps*) Bregetova, 1977a: 527.

Androlaelaps Hughes, 1948: 136; Bregetova, 1955a: 233, 1955b: 313, 1956: 71; Zhang et al., 1963: 193; Karg, 1971: 185.

Hypoaspis Karg, 1971: 160; Hughes, 1976: 292; Zaher, 1986: 185; Deng et al., 1993: 157.

Euandrolaelaps Casanueva, 1993: 40; Hajizadeh and Joharchi, 2018: 26; Babaeian et al., 2019: 333; Moraes et al., 2022: 238; Bandyopadhyay et al., 2023: 406.

***Diagnosis*:** Fixed digit of chelicera features three prominent teeth situated distally to pilus dentilis, followed by a series of approximately seven to nine smaller, subsidiary teeth. Palp tarsal claw exhibits bifid morphology; trifid occasionally. Dorsal idiosomal shield sub-oval shaped, bearing 37-39 pairs of moderate sized setae; comparable in length. Presternal region adorned with lineate reticulations and exhibits minimal level of sclerotization; features discrete platelets. Maximum width of pyriform epigynal shield discernible at the level of *ZV1* or posteriorly, measuring slightly more than twice the width of narrow constriction/ neck positioned between coxae IV. Setae *st5* and *ZV1* inserted along the edges of epigynal shield, (except *E. karawaiewi*, *ZV1* positioned off the shield). Epigynal shield demarcated from anal shield by approximately half the length of anal shield or less. Peritreme elongated, extends anteriorly to level with coxa I or reaching the anterior edge of coxa II. Unsclerotized dorsolateral and opisthogastric regions features up to seven pairs of lateral setae ranging from *r6* to *R6* and seven to nine pairs of setae from *JV*, *ZV* series (excluding *ZV1* positioned on the epigynal shield). Leg II exhibit numerous robust setae modified into spurs or spines, prominently distributed from femur to tarsus. Genu IV equipped with 10 setae, including two posterior lateral setae; tibia III provided with 9 setae and 2 posterior lateral setae.

Type species: *Laelaps* (*Androlaelaps*) *sardous* Berlese, 1911,

Euandrolaelaps karawaiewi (Berlese, 1904)

PLATE 5

Laelaps (*Androlaelaps*) *karawaiewi* Berlese, 1904: 432.

Androlaelaps karawaiewi Vitzthum, 1921: 22; Radford, 1950: 366; Willmann, 1951: 146; Bregetova, 1956: 83; Till, 1963: 12; Karg, 1971: 185; Ren and Guo, 2009: 100; Lin et al., 2013: 159; Zhou et al., 2015: 488.

Hypoaspis (*Androlaelaps*) *karawaieni* Zumpt and Patterson, 1950: 67.

Hypoaspis karawaiewi Costa, 1968: 7.

Hypoaspis (*Euandrolaelaps*) *karawaiewi* Bregetova, 1977a: 530; Sklyar, 2001: 101.

Euandrolaelaps karawaiewi Kazemi and Rajaei, 2013: 80; Hasanvand et al., 2014: 95; Amani et al., 2015: 92; Kordeshami et al., 2015: 591; Maleki et al., 2016: 187; Hajizadeh and Joharchi, 2018: 26; Nemati et al., 2018b: 137; Babaeian et al., 2019: 333; Moraes et al., 2022: 238.

Diagnosis

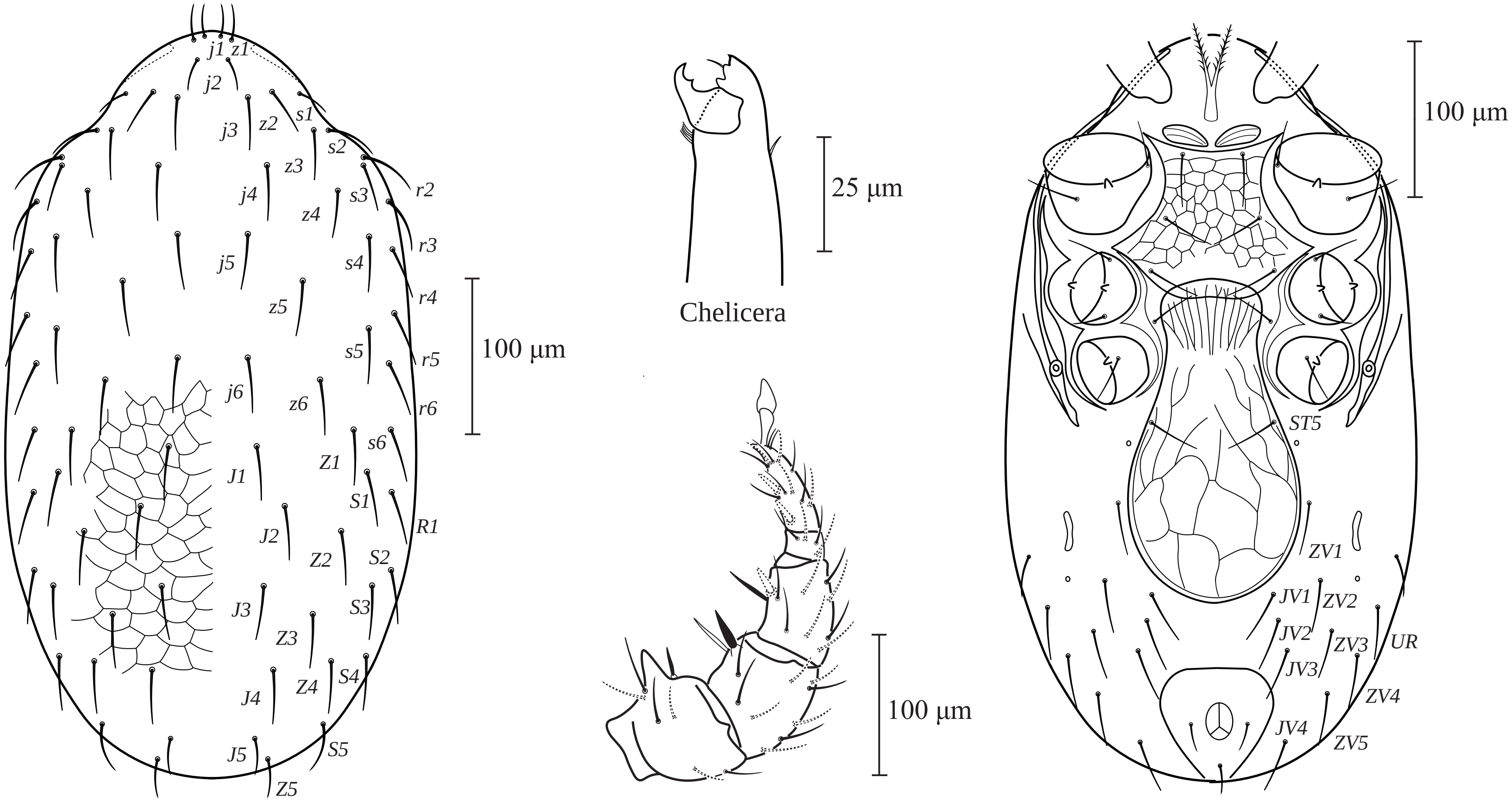
Female: Size of idiosoma: 472 x 236 µm. Body exhibits robust sclerotization. Chelicera features diminutive digits; movable digit bears a single tooth and the fixed digit exhibits two teeth, with the apical tooth excluded in either count. Anterior hypostomal setae *hyp1* conspicuously elongated. Narrow and long corniculi project beyond the midpoint of palp femur. Pedipalp apotele two-tined. Dorsal shield adorned with intricate reticulation, featuring 39 pairs of fine setae. Sternal shield displays prominent reticulations, equipped with three pairs of sternal setae (*st1*-*st3*) accompanied by well demarcated pre-endopodal plates. Metasternal setae positioned on the soft cuticle, exopodal and endopodal shields present. Peritremes elongated, extending to the base of prodorsal setae *z1*. Pyriform sacculus foemineus present. Femur II with a robust, fixed protrusion. Genu and tibia II possess a single, prominent, proximally expanded and distally tapered, stout seta on ventral surface; tarsus II bears two similar setae ventrally.

Male: Not obtained

Material examined:

- One female specimen from Kannur (Supplyco supermarket- Cherupuzha, 12° 16' 29.58''N, 75° 21' 51.39'' E), collected from stored boiled rice on 31 May 2019 by Neeraj Martin.

PLATE 5



Dorsum | Chelicera | Leg II | Ventrum

***Euandrolaelaps karawaiewi* (Berlese, 1904), Adult female**

Euandrolaelaps sardous (Berlese, 1911)

PLATE 6

Laelaps (*Androlaelaps*) *sardous* Berlese, 1911: 433

Androlaelaps pilifer Oudemans, 1912: 262, 1914: 179; Vitzthum, 1921: 22; Hughes, 1948: 136; Turk and Turk, 1952: 483; Zumpt and Till, 1953a: 215.

Androlaelaps sardous Vitzthum, 1929: 27; Willmann, 1952a: 425; Wolf, 1938: 644; Sellnick, 1940: 28; Radford, 1950: 366; Bregetova, 1956: 83; Piryanik, 1962: 83; Till, 1963: 12; Ambros, 1983a: 202, 1983b: 144; Castagnoli and Pegazzano, 1985: 369.

Hypoaspis (*Androlaelaps*) *sardous* Zumpt and Patterson, 1950: 67.

Hypoaspis sardoa Evans and Till, 1966: 175; Beron, 1974: 180; Hughes, 1976: 297; Nawar et al., 1993: 347

Hypoaspis (*Euandrolaelaps*) *sardous* Bregetova, 1977a: 530.

Hypoaspis (*Alloparasitus*) *sardoa* Karg, 1979: 76, 1993: 140; Tenorio et al., 1985: 300; Gwiazdowicz and Gulvik, 2005: 119; Keum et al., 2016: 478.

Alloparasitus sardous Farrier and Hennessey, 1993: 64; Bernini et al., 1995: 27

Euandrolaelaps sardoa Kazemi and Rajaei, 2013: 80; Mahjoori et al., 2014: 1603; Nemati and Gwiazdowicz, 2016a: 44; Hajizadeh and Joharchi, 2018: 26; Nemati et al., 2018b: 138;189.

Euandrolaelaps sardous Moraes et al., 2022: 239; Bandyopadhyay, 2023: 406.

Diagnosis

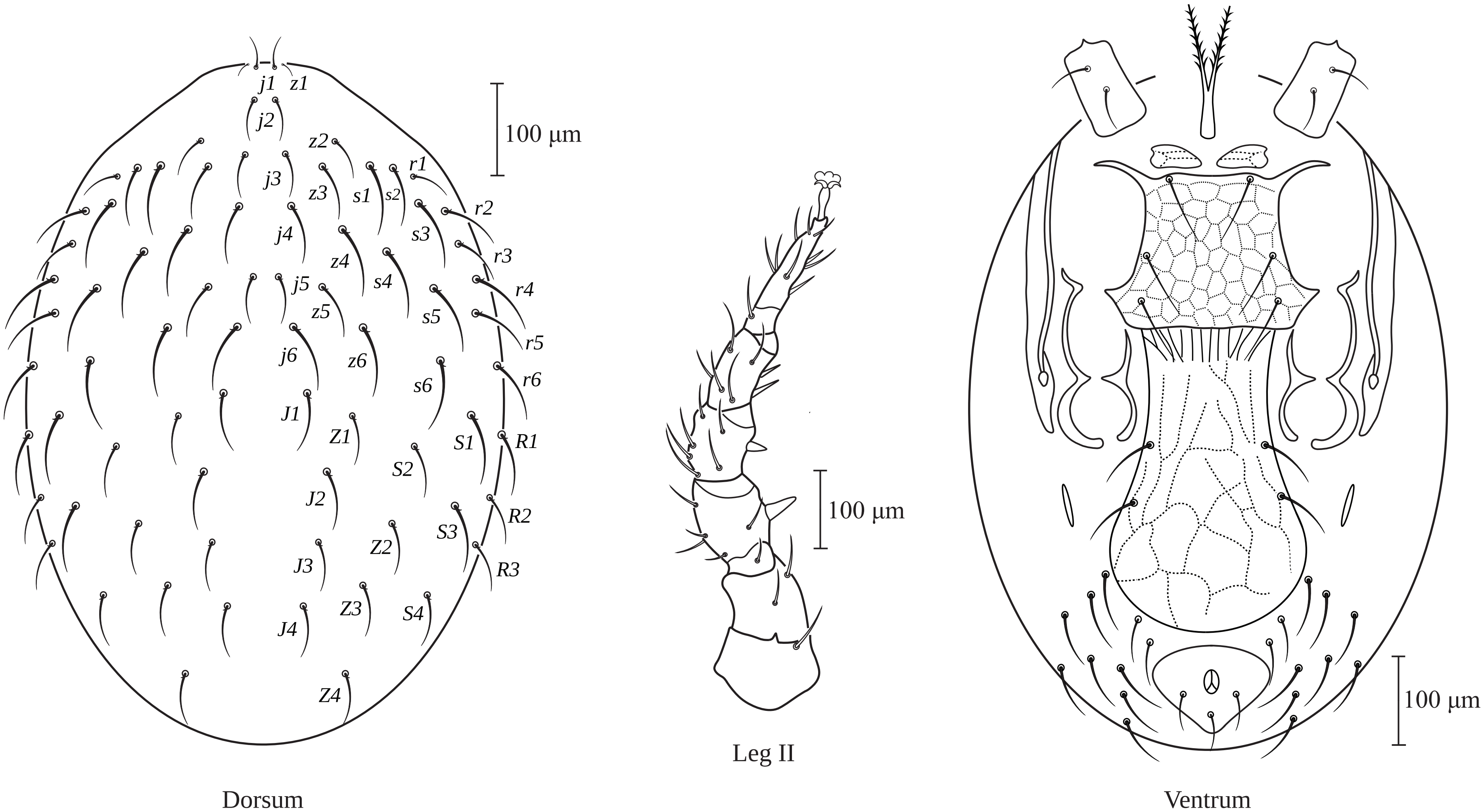
Female: Size of idiosoma: 472 x 236 µm. Gnathotectum exhibits a rounded outline, displaying denticulate margines anteriorly, and marked with longitudinal striations. Corniculi elongated conspicuously. Cheliceral fixed digit features three teeth followed a row of diminutive teeth and possesses a reduced setiform pilus dentilis. Movable digit possesses two teeth. Palp femur bears two setae, palp genu with five setae, palp tibia features six setae and palp tarsus equipped with fourteen setae; apotele two tined. Dorsal idiosomal shield glabrous, features 39 pairs of setae. Prominently demarcated and distinct pre-endopodal plates present, delineated from each other. Sternal shield equipped with *st1-st3* and two pairs of pores. Pyriform genital shield comprises two pairs of setae. Metasternal setae positioned on interscutal membrane. Peritrematal and exopodal plates remains distinct and non-confluent. Anterior end of peritrematal plate coalesced with dorsal shield; peritreme reaches to the anterior proximity of coxa II. Anal shield complemented with three circum-anal setae. Diminutive metapodal plates present. Ventral plates adorned with reticulations. Leg chaetotaxy deviates from the typical arrangement by featuring an extra posterolateral seta on tibia III and genu IV. Femur II possess a single, prominent, non- articulated stout horn like seta on ventral surface; a similar, but relatively shortened seta present on genu II. Tibia II features two similar setae ventrally.

Male: Not obtained.

Material examined:

- One female specimen from Malappuram (Grocery store- Tirur 10° 54' 55.89" N, 75° 55' 21.21" E), collected from stored boiled rice on 10 June 2022 by Neeraj Martin.

PLATE 6



Euandrolaelaps sardous **(Berlese, 1911), Adult female**

Genus *Stratiolaelaps* Berlese, 1916

Hypoaspis (*Stratiolaelaps*) Berlese, 1916: 168.

Laelaps (*Eulaelaps*) Berlese, 1903: 13.

Stratiolaelaps Vitzthum, 1931: 143; Radford, 1950a: 20; Evans, 1957: 221; Hughes, 1961: 217; Athias-Henriot, 1968: 239; Evans and Till, 1979: 201; Zaher, 1986: 198; Domrow, 1988: 825; Casanueva, 1993: 40; Walter and Campbell, 2003: 256; Karg and Schorlemmer, 2013: 202; Gwiazdowicz et al., 2014: 441; Nemati and Gwiazdowicz, 2016: 548; Hajizadeh and Joharchi, 2018: 25; Moraes et al., 2022: 109, 386.

Hypoaspis (*Stratiolaelaps*) Vitzthum, 1942: 763; Baker and Wharton, 1952: 94; Evans and Till, 1966: 160; Hughes, 1976: 292; Bregetova, 1977a: 510.

Hypoaspis (*Cosmolaelaps*) Schweizer, 1961: 149; Karg and Schorlemmer, 2009: 61; Huhta and Karg, 2010: 330.

*Cosmolaelap*s Bregetova, 1955b: 290; Zhang et al., 1963: 191.

Diagnosis: Corniculi elongated, extending approximately to the distal extremity of palp femur. Hypostomal seta *h1* markedly longer than *h3*. Palp tarsal claw typically bifid, occasionally trifid with a diminutive third tine. Chelicerae composed of prominently elongated digits. Fixed digit exhibits three moderately sized teeth; two positioned subapically and one situated near proximity to pilus dentilis. Fixed digit occasionally comprises an additional row of 3-4 diminutive denticles, on proximal chelicerae. Dorsal idiosomal shield attenuating gradually or promptly in the opisthonotal region or caudal third, ornamented with prominent reticulations, featuring 37-39 pairs of lanceolate or spatulate-apiculate tricarinate setae (occasionally bearing two to three additional setae on opisthonotal *Z* series). Membranous dorsolateral and opisthogastric cuticle features holotrichy; comprising prodorsal marginal seta *r*6 and 6-7 opisthodorsal marginal setae (*R*) and 3-6 or exceptionally numerous posterior submarginal setae (*UR*) symmetrically. Ventrum with linguiform epigynal shield and pyriform (occasionally rhombus shaped) anal shield. Presternal ridges coalesced with 3-4 pairs of ridges, exhibiting variable sclerotization; appearing as narrow-platelets. Sternal shield distinguished by expanded robust endopodal anterior lateral arms positioned between coxae I and II. Peritrematal shield expanded and adorned with reticulation. Leg setation normal; segments display a wrinkled appearance.

Type species: *Laelaps* (*Iphis) miles* Berlese, 1892

Stratiolaelaps scimitus (Womersley, 1956)

PLATE 7

Cosmolaelaps scimitus Womersley, 1956: 580.

Hypoaspis (*Stratiolaelaps*) *miles elsi* Aswegen and Loots, 1970: 205.

Hypoaspis (*Cosmolaelaps*) *scimitus* Karg, 1978: 8.

Hypoaspis (*Cosmolaelaps*) *scimita* Karg, 1979: 71;1988: 512; Tenorio et al., 1985: 300; Huhta and Karg, 2010: 330.

Stratiolaelaps miles Domrow, 1988: 846; Shaw, 1999: 45.

Cosmolaelaps scimitus Farrier and Hennessey, 1993: 69.

Hypoaspis (*Stratiolaelaps*) *antennata* Karg, 1993a: 262.

Stratiolaelaps scimitus Strong and Halliday, 1994: 87; Walter and Campbell, 2003: 266; Faraji and Halliday, 2009: 260; Kazemi et al., 2014: 510; Moreira et al., 2014: 322; Kontschán et al., 2016: 25; Moraes et al., 2016: 392; Nemati et al., 2018b: 150.

Diagnosis

Female: Mean size of idiosoma: 256 x 184 μm. Cheliceral digits robust, prominently elongated and equal in length. Fixed digit of chelicera features two teeth with considerable interspace, aligned anterior to setiform pilus dentilis and posteriorly bear two reduced teeth, leading into a shearing edge proximally. Movable digits equipped with two distantly spaced teeth. Gnathotectum exhibits serrated margins with a spinous protrusion at medial axis. Corniculi distinctly elongated, reaching the distal extremity of palp femur. Palp apotele features two similar sized tines; complemented by an inconspicuous, diminutive tine, positioned proximally. Dorsal idiosomal shield tapers abruptly posterior to the level of setae *S2*. The shield provided with 37 pairs of setae comprising 22 pairs of podonotal setae (including *r2-r6*) and 15 pairs of opisthonotal setae. Dorsal setae predominantly spatulate-apiculate in morphology. Setae *j1* similar in length to *z1*. Setae *J5* linear, featuring a barbed shaft, comparable in length to *J4*. Ventral setae *JV1*, *JV2*, *ZV1* and *ZV2* acuminate, significantly differing from spatulate-apiculate setae positioned on membranous integument. Paranal and postanal seta acuminate, comparable in length.

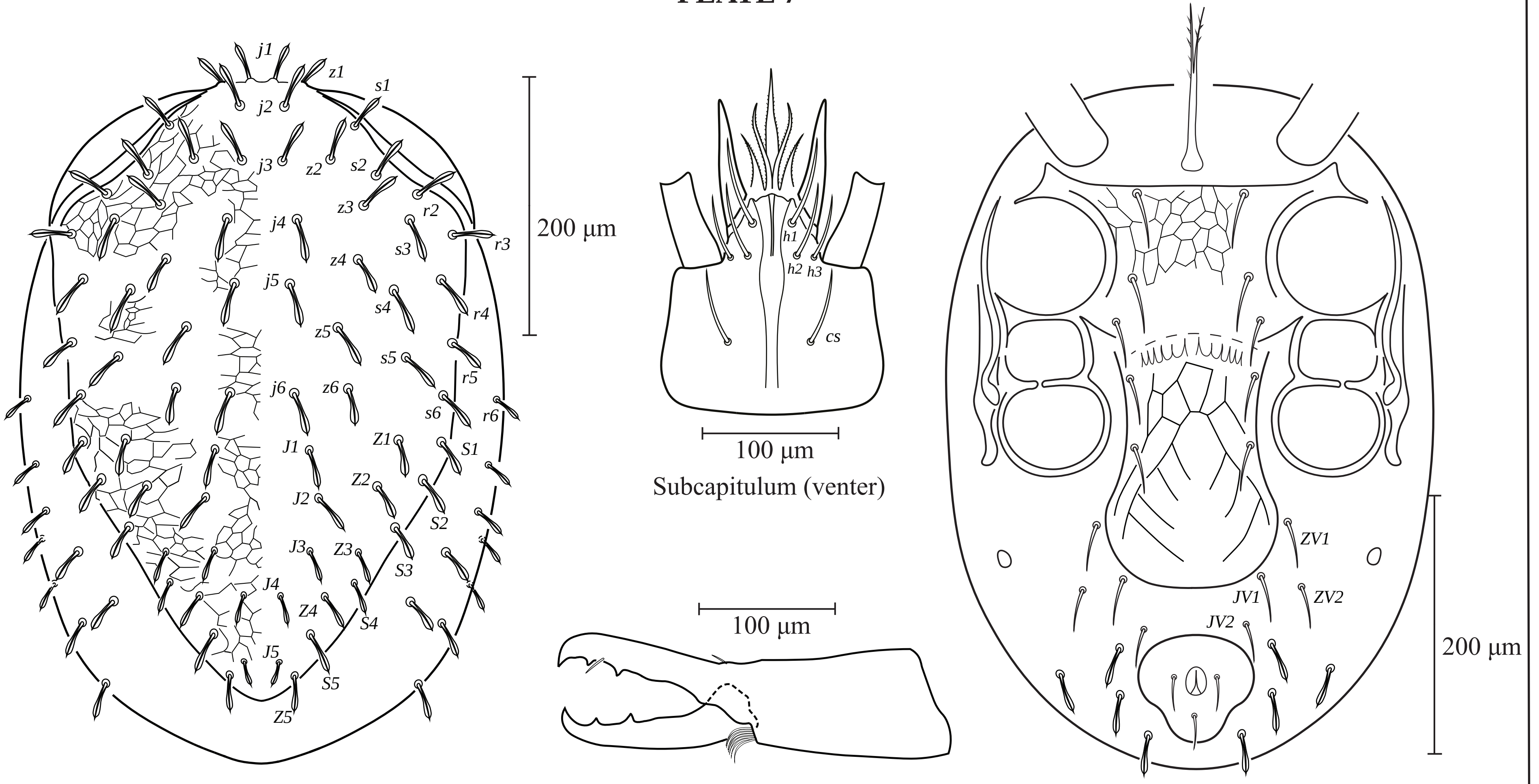
Male: Not obtained.

Material examined:

- Two female specimen from Kozhikode (Market Warehouse, 11° 14' 56.4" N, 75° 46' 38.0" E), collected from stored foxtail millet on 4 December 2018 by Neeraj Martin.
- One female specimen from Kozhikode (Chethukadavu, 11° 18' 46.5" N, 75° 54' 8.9" E), collected from stored chickpea on 14 October 2019 by Neeraj Martin.
- One female specimen from Kannur (Central warehousing corporation Warehouse-Dharmashala, 11° 58' 59" N, 75° 22' 36" E), collected from stored boiled rice on 12 February 2020 by Neeraj Martin.
- One female specimen from Kasaragod (Kanhangad, 12°17'20.1" N 75°08'05.7" E), collected from stored rice flakes on 09 February 2021 by Neeraj Martin.

III

PLATE 7



Dorsum Chelicera Ventrum

Stratiolaelaps scimitus **(Womersley, 1956), Adult female**

4.2.3.2. Family Blattisociidae Garman, 1948

Gamasidae Leach, 1815: 396; Hirschmann, 1962: 38.

Seiidae Berlese, 1913a: 12.

Ascaidae (Oudemans, 1905) Bernhard, 1963: 33.

Podocinidae Berlese, 1916: 33; Westerboer, 1963: 179; Karg, 1971: 100; 1976: 508.

Podocininae Vitzthum, 1941: 765; Baker and Wharton, 1952: 89.

Blattisociinae Garman, 1948: 18.

Laelapidae Nesbitt, 1951: 1.

Aceosejidae Evans, 1957: 224; Athias-Henriot, 1957: 326; 1968: 232; Baker et al., 1958: 28; Hughes, 1961: 224; Krantz, 1962: 4; Bregetova, 1977: 169.

Aceosejinae Evans, 1957: 226; 1958: 177; Karg, 1962: 35; Evans, 1963: 302; Krantz, 1962: 4.

Platyseiinae Evans, 1957: 225.

Melicharinae Hirschmann, 1962: 38.

Platyseiinae Krantz, 1962: 4; Lindquist, 1964: 72; 2003: 157; Lindquist and Evans, 1965: 36; Zaher, 1986: 47.

Blattisociinae Chant, 1963: 243; Lindquist, 1964: 74; Karg, 1965: 307; 1993: 171.

Blattisociidae Lindquist, 1964: 68; Athias-Henriot, 1973: 227; Lindquist et al., 2009: 164; Lindquist and Moraza, 2010: 2; Moraes et al., 2016:10.

Ascidae Lindquist and Evans, 1965: 5; Karg, 1971: 81Zaher, 1986: 39; Farrier and Hennessey, 1993: 22; Halliday et al., 1998: 1; Kalúz and Fenďa, 2005: 39

Ascinae Lindquist and Evans, 1965: 38; Zaher, 1986: 49.

Blattisociini Lindquist and Evans, 1965: 45.

Blattisocinae Karg, 1971: 81.

Phytoseiidae Karg, 1993: 171; Muma, 1961: 270.

***Diagnosis*:** Deutosternum moderately to distinctly wide, featuring lateral delimiting lines. Palp tarsal apotele bifurcated. Cheliceral digits comparable in length; fixed digit shortened in *Blattisocius*. Fixed digit typically features 4 to 20 teeth in addition to the apical tooth; movable digit equipped with up to 4 teeth. Spermatodactyl length varies, ranging from equal to movable digit to approximately four times its length. Idiosomal shape variable, elongate to hemispherical. Podonotum and opisthonotum enveloped by a single, integrated shield, featuring a glabrous or ornamented surface. Podonotum provided with 15-25 pairs of setae, opisthonotum bears 8-16 pairs. Lateral membranous integument complemented with a variable number of setal pairs, ranging from 0 to 16; rarely 20. Posterior submarginal setae variably present or absent. Ventrum features 0-3 pairs of distinct presternal plates or a coalesced, sclerotized parasternal region, integrate with sternal shield. Sternal shield usually equipped with *st1*- *st3*; only 1 to 2 pairs occur in *Blattisocius*, with varying lengths and shapes. Genital shield generally contains *st5*, and *iv5* positioned off the shield. Male sternigenital shield contains 4 to 5 pairs of setae with *st5* positioned off the shield in *Blattisocius*. Male ventrianal shield usually features 4 to7 pairs of setae, along with circumanal setae. Peritreme typically extends from stigma to *s2*. Peritrematic shield commonly wide (narrow in *Blattisocius*), coalescing anteriorly with the dorsal shield and posteriorly with the exopodal shield in the proximity of coxa IV. All legs feature pretarsi. Typical leg chaetotaxy range: genu I-IV: 12-13, 10-11, 8-9, 8-10; tibia I-IV: 12-13, 9-10, 8-9, 9-10. Presence of macrosetae on leg variable. Spermathecal apparatus Phytoseiid type. Leg II of males may feature some spike or horn shaped setae.

Type genus: *Blattisocius* Keegan, 1944.

Genus *Blattisocius* Keegan, 1944

Blattisocius Keegan, 1944: 181.

Garmania (*Paragarmania*) Nesbitt, 1951: 49; Evans, 1958: 206.

Blattisocius Nesbitt, 1951: 51; Athias-Henriot, 1957: 331; Evans, 1957: 227; Hirschmann, 1959: 7; Bernhard, 1963: 34; Chant, 1963: 297; Lindquist, 1964: 181; Lindquist and Evans, 1965: 48; Hughes, 1976: 324; Karg, 1993: 171; Bregetova, 1977: 225; Evans and Till, 1979: 199; Zaher, 1986: 78; Farrier and Hennessey, 1993: 29; Halliday et al., 1998: 17; Gupta, 2003: 2; Gwiazdowicz et al., 2008: 35; Moraza and Lindquist, 2011: 3; Moraes et al., 2016: 34,132.

Paragarmania Evans, 1957: 227; Karg, 1965: 203; 1993: 171; Bregetova, 1977: 222; Halliday et al., 1998: 17.

Melichares Evans, 1958: 206; Hughes, 1961: 232.

Melichares (*Blattisocius*) Evans, 1958: 208; Athias-Henriot, 1959: 161; Hughes, 1961: 232; Lindquist, 1964: 181

Diagnosis: Cheliceral digits variable in length, fixed digit comparable in length to movable digit or significantly shorter. Fixed digit typically bears 0-5 teeth in females and 0-10 teeth in males, excluding the apical tooth in both sexes. Movable cheliceral digit possess 0-3 teeth in females and 0-1 teeth in males (except *B. tarsalis,* bears 3-4 teeth) all in addition to the apical tooth. Spermatodactyl exceeds the length of movable digit, features a subapically pointed ventral prominence and exhibit subtle downward curvature. Idiosoma oval shaped. Dorsal idiosomal shield ornamented, males possess distinctly broader shield than females, comprising an elevated count of *r-R* setae. Podonotum provided with 16-20 one pairs of setae, including horizontally oriented *r3*. Opisthonotum typically bears 15 pairs of setae. Most dorsal and lateral setae of idiosoma comparable in length, acicular and smooth; minimally serrated rarely, but devoid of tricarination. Presternal area typically features transverse lines. Setae *st4* situated on membranous integument (except *B. dentriticus, st4* positioned on narrow platelet). Genital and ventrianal shields demarcated by a sclerotized line. Males bear enlarged ventrianal shields. Endopodal shield (when properly formed) confluent with sternal shield anteriorly, or intercoxal projections (between I-II and II-III) of endopodal shield (when under developed) become less prominent or obsolete. Peritreme varies in length, extending to posterior edge of coxae III in short forms or to anterior edge of coxae I in long forms. Spermathecal apparatus phytoseiid-type. Chaetotaxy of legs I-IV, femur: 12-11-6-6, genu: 13-11-9-9 and tibia: 13-10-8-10. Leg II not markedly robust, macrosetae inconsistently present on Leg IV.

Type species: *Blattisocius triodons* Keegan, 1944

Key to the species belonging to the genus *Blattisocius* obtained from the present study

1. Cheliceral fixed and movable digit subequal in length; peritreme long, nearly reaching anterior margin of coxa II…...…………………..…*Blattisocius dentriticus* Berlese, 1918
- Cheliceral fixed digit shorter than movable digit; peritreme short, not reaching anterior margin of coxa II ……………………………..…………………………………..…....2
2. Peritreme reaching posterior margin of coxa II; cheliceral movable digit with three teeth, Dorsal setae *J3–J5* and *Z5* smooth…..…...……….…… *B. tarsalis* (Berlese, 1918)
- Peritreme reaching posterior margin of coxa III; cheliceral movable digit with one tooth, Dorsal setae *J3–J5* and *Z5* pilose ………..…..................…*B. keegani* Fox, 1947

Blattisocius dentriticus Berlese, 1918

PLATE 8

Lasioseius (*Lasioseius*) *dentriticus* Berlese, 1918: 133.

Lasioseius fimbriatus Halbert, 1923: 368.

Garmania fimbriatus Evans, 1954: 796.

Garmania (*Paragarmania*) *amboinensis* Nesbitt, 1951: 50; Cunliffe and Baker, 1953: 6; Evans, 1954: 796.

Melichares (*Blattisocius*) *dentriticus* Evans, 1958: 211; Athias-Henriot, 1959: 162; Ehara, 1961: 96; Hughes, 1961: 238.

Melichares dentriticus Burnett, 1960: 234; Hirschmann, 1962: 30.

Paragarmania dentriticus Westerboer, 1963: 278; Karg, 1965: 207; Bregetova, 1977: 224; Christian and Karg, 2008: 69.

Melichares dendriticus Costa, 1966: 71.

Blattisocius dentriticus Chant, 1963: 300; Ehara, 1964: 391; Lindquist, 1964a: 198; Lindquist and Evans, 1965: 48; Ishikawa, 1969: 118; McGraw and Farrier, 1969: 52; Treat, 1975: 90; Haines, 1979: 26; Hughes, 1976: 329; Zaher, 1986: 79; Farrier and Hennessey, 1993: 29; Halliday, 1998: 117; Halliday et al., 1998: 18; Gwiazdowicz, 2007: 64; Zhang and Fan, 2010: 282; Britto et al., 2012: 50; Moraes et al., 2016: 133.

Paragarmania dentritica Karg, 1993: 172; Christian and Karg, 2006: 238.

Seiulus amboinensis Oudemans, 1925: 30.

Typhlodromus amboinensis Buitendijk, 1945: 301.

Diagnosis

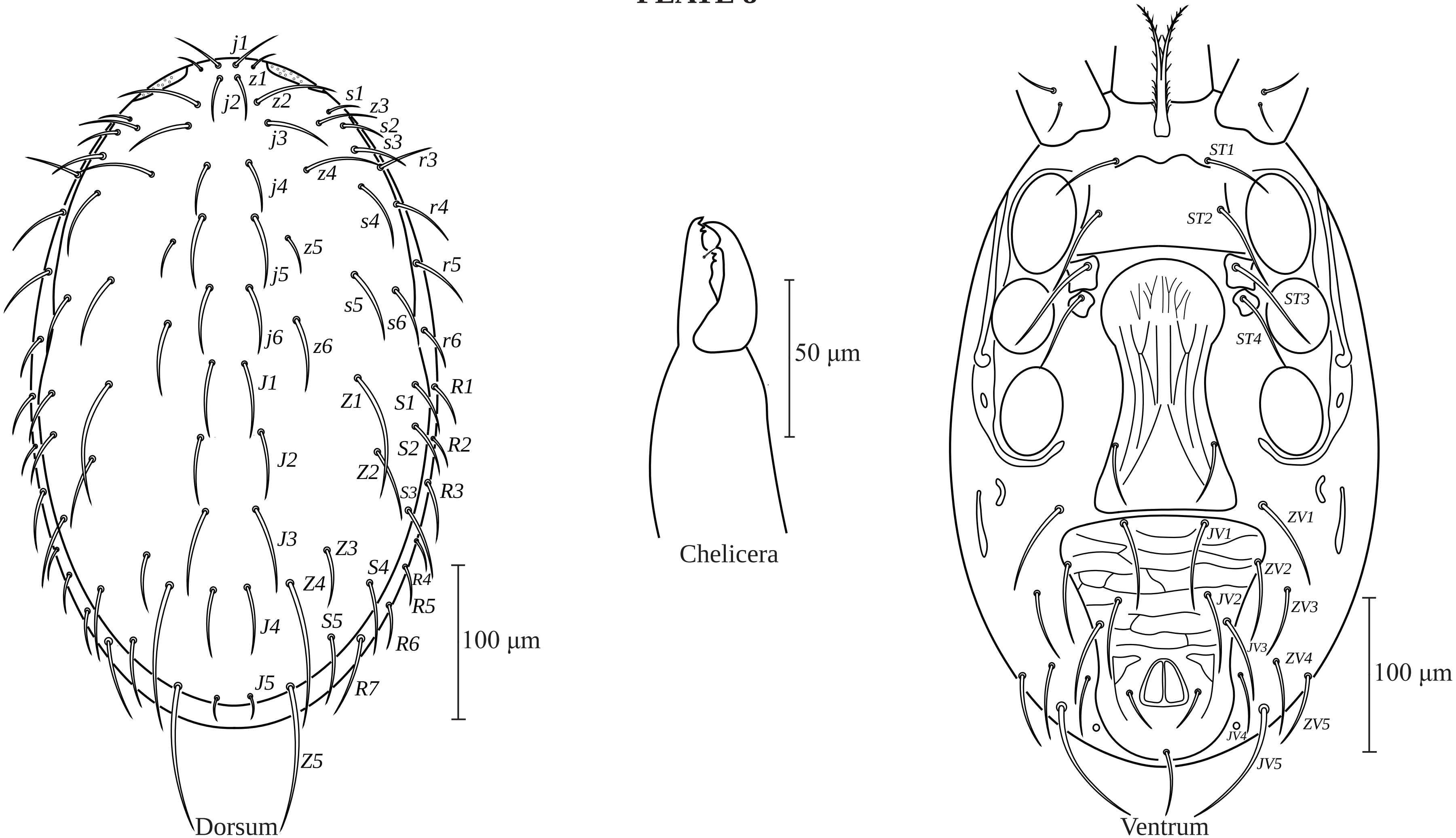
Female: Mean size of idiosoma: 426 x 252 µm. Gnathotectum with smooth and rounded margin; corniculi slender, convergent. Fixed and movable cheliceral digits approximately equal in length and exhibit toothed margins. Dorsal idiosomal surface predominantly obscured by a delicately reticulated shield, bearing 36 pairs of dorsal setae, including 15 pairs arising from the posterior region. Dorsal setae exhibit smooth, curved morphology. Dorsal setae *Z4* and *Z5* exhibit pronounced elongation, whereas *J5* appears reduced and diminutive, situated at the posterior extremity of the shield. Seven pairs of marginal setae (*R1-R7*) occupy the interscutal membrane, extending beyond the posterior midpoint of the shield. Anterior segment of the sternal shield features a delicate reticulate pattern, bearing two pairs of sternal setae, whereas the third pair and metasternal setae originate from discrete shields. Genital shield, together with the ventri-anal shield, displays a delicately reticulated surface, accommodating four pairs of pre-anal setae. Interscutal membrane bears three pairs of setae posterior to the ventri-anal shield and accompanied by a conspicuously elongated pair (*JV5*). Peritrematal plate extends rearward, abutting the exopodal region and surrounds the posterior margin of coxa IV. Two slender metapodal plates present. Tarsus IV with a long macroseta, basally inserted.

Male: Not came in collection.

Material examined:

- One female specimen from Kozhikode (Central warehousing corporation-West Hill, 11° 17' 0" N, 75° 45' 43" E), collected from boiled rice on 24 January 2019 by Neeraj Martin.
- Two female specimen from Kannur (Food Corporation of India –Payyannur, 12° 05' 02.52" N, 75° 11' 58.56"), collected from stored wheat on 16 July 2021 by Neeraj Martin.
- Two female specimen from Kasaragod (Supplyco taluk depot- Kanhangad, 12° 18' 35" N, 75° 5' 29" E), collected from stored mustard on 04 August 2021 by Neeraj Martin.
- Two female specimen from Palakkad (State warehousing Corporation –Thayilpetti, 10° 45' 59.96" N, 76° 39' 17.02" E), collected from stored raw rice on 23 September 2022 by Neeraj Martin.

PLATE 8



***Blattisocius dentriticus* Berlese, 1918, Adult female**

Blattisocius keegani Fox, 1947

PLATE 9 A, B

Blattiosocius keegani Fox, 1947: 599.

Blattisocius keegani Cunliffe and Baker, 1953: 7; Athias-Henriot, 1957: 331; Chant, 1963: 300; Lindquist, 1964: 194; Prasad, 1968: 132; McGraw and Farrier, 1969: 55; Karg, 1993: 172; Treat, 1975: 94; Baker et al., 1976: 59; Hughes, 1976: 328; Bregetova, 1977: 226; Haines, 1979: 21; Zaher, 1986: 82; Farrier and Hennessey, 1993: 29; Halliday, 1998: 118; Halliday et al., 1998: 19; Kamali et al., 2001: 6; Gwiazdowicz, 2007: 65; Zhang and Fan, 2010: 282; Britto et al., 2012: 43; Esteca et al., 2014: 361; Moraes et al., 2016: 135.

Melichares (Blattisocius) *keegani* Evans, 1958: 209; Athias-Henriot, 1959: 162; Hughes, 1961: 237.

Melichares keegani Hirschmann, 1962: 30, Sinha et al., 1962: 546.

Diagnosis

Female: Size of idiosoma: 356 x 176 µm. Dorsal shield features 33 pairs of setae, encompassing setae *s2* and exhibit reticulate pattern. Unsclerotised cuticle of dorsal idiosoma equipped with 11 pairs of marginal (*r2* to *R7*) setae followed by six pairs of submarginal (*UR1* to *UR6*) setae. Sternal and genital shield exhibits a truncated posterior margin and marked with sinuous longitudinal striae. Two pairs of metapodal plates present. Ventrianal shield approximately pentagonal in outline, covered with reticulations, and bears three pairs of opisthogastric setae. Peritremes significantly shortened, extending anteriorly from coxae IV and terminating at the median level of coxa III. Fixed cheliceral digit distinctly shorter than movable digit, bearing four teeth including apical tooth, with sharp and needle-like pilus dentilis. Movable digit of chelicera possesses one robust tooth excluding the apical tooth. Spermathecal receptacle assumes a corniform shape, displaying multiple narrowings proximal to the reservoir; the atrial region spheroidal.

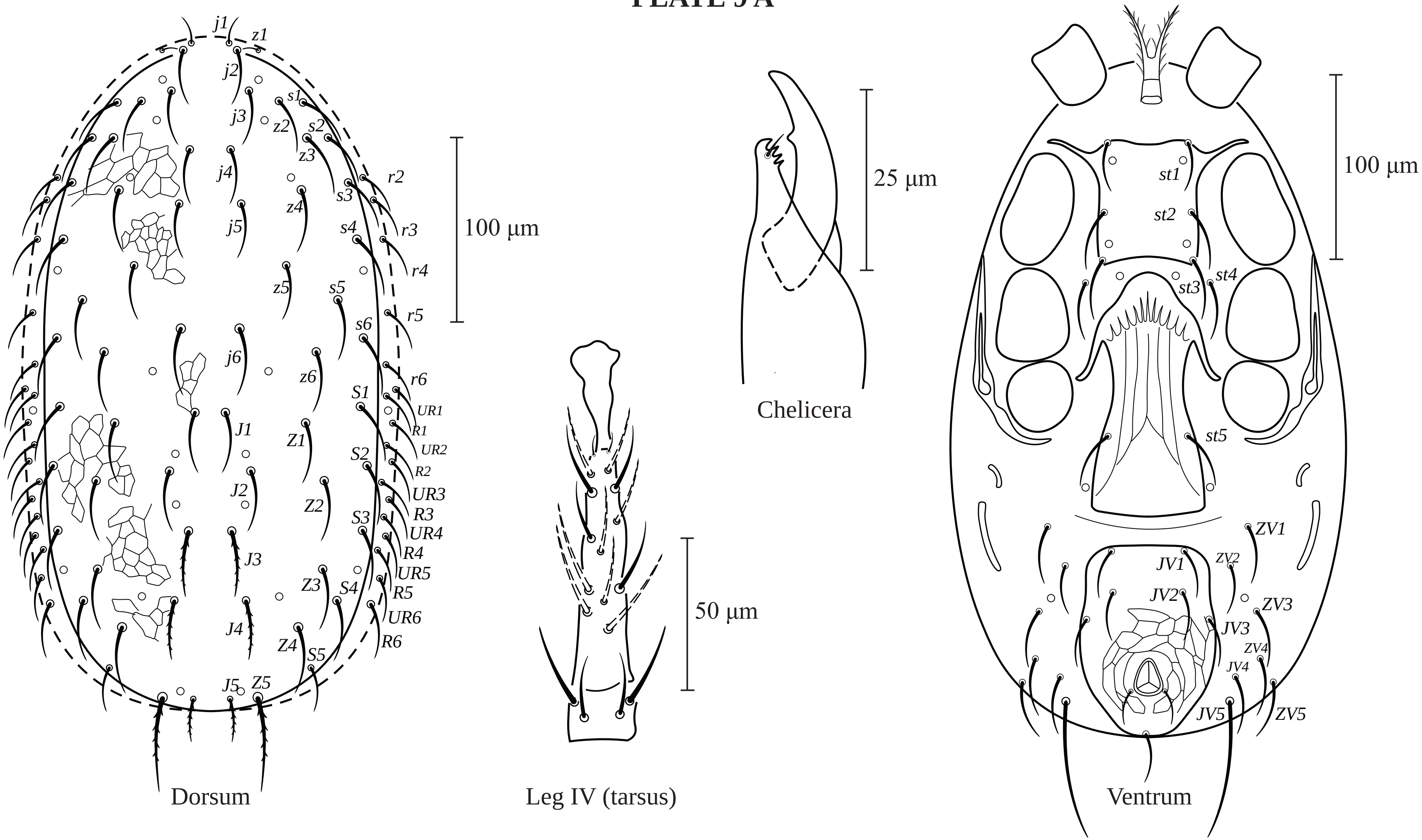
Male: Mean size of idiosoma: 458 x 234 µm. Dorsal shield reticulation, setal number, arrangement, *s2* insertion, and setal morphology and lengths similar to females. Sternogenital shield exhibits scattered cuticular striations and features a recessed area posterior to *st4*. Ventrianal shield approximately semiglobular, displaying reticulations and bearing six pairs of opisthogaster setae. Cheliceral fixed digit with 2-3 teeth (excluding apical tooth) and equipped with setiform pilus dentilis. Movable digit bears one thickened tooth, excluding the apical tooth. Distal region of the spermadactyl recurved, possessing a dorsal membranous expansion, a ventral subterminal spine-like outgrowth, and terminating in a concave apex

Material examined:

- Three female specimen from Kozhikode (Market warehouse, 11° 14' 56.4'' N, 75° 46' 38.0'' E), collected from stored Cumin seeds, mustard and Foxtail millet on 04 December 2018 by Neeraj Martin.
- One male specimen from Kozhikode (Food Corporation of India Warehouse -West Hill, 11° 17' 14.0'' N, 75° 45' 56.0'' E), collected from stored wheat on 23 January 2019 by Neeraj Martin.
- One female specimen from Kozhikode (Supplyco Depot Warehouse-Thamarassery, 11° 23' 26'' N, 75° 55' 18'' E), collected from stored mustard on 12 February 2019 by Neeraj Martin.
- One female specimen from Kozhikode (Supplyco Depot Warehouse- Thamarassery, 11°22'16.2"N 75°54'33.4"E), collected from stored chick pea on 12 February 2019 by Neeraj Martin.
- One female specimen from Wayanad (Supplyco PDS Depot- Bathery, 11° 39' 13.51'' N, 76° 15' 28.07'' E), collected from stored pepper on 3 April 2019 by Neeraj Martin.
- One female specimen from Kasargod (Food Corporation of India- Nileshwar, 12° 15' 27.84'' N, 75° 08' 05.60'' E), collected from stored raw rice on 19 November 2019 by Neeraj Martin.
- One female specimen from Kozhikode (Food Corporation of India Warehouse-Thikkodi, 11° 29' 40'' N, 75° 37' 34'' E), collected from stored boiled rice on 17 May 2019 by Neeraj Martin.
- Two female specimen from Kozhikode (Food Corporation of India Warehouse -West Hill, 11° 17' 14.0'' N, 75° 45' 56.0'' E), collected from stored wheat on 18 December 2020 by Neeraj Martin.
- Two female specimen from Wayanad (Supplyco Depot Warehouse- Kalpetta, 11°37'36.2"N, 76°04'15.3"E), collected from stored black gram on 06 January 2021 by Neeraj Martin.
- One female specimen from Wayanad (Food Corporation of India Warehouse- Meenangadi, 11°39'18.6"N 76°09'22.2"E), collected from stored wheat on 06 January 2021 by Neeraj Martin.

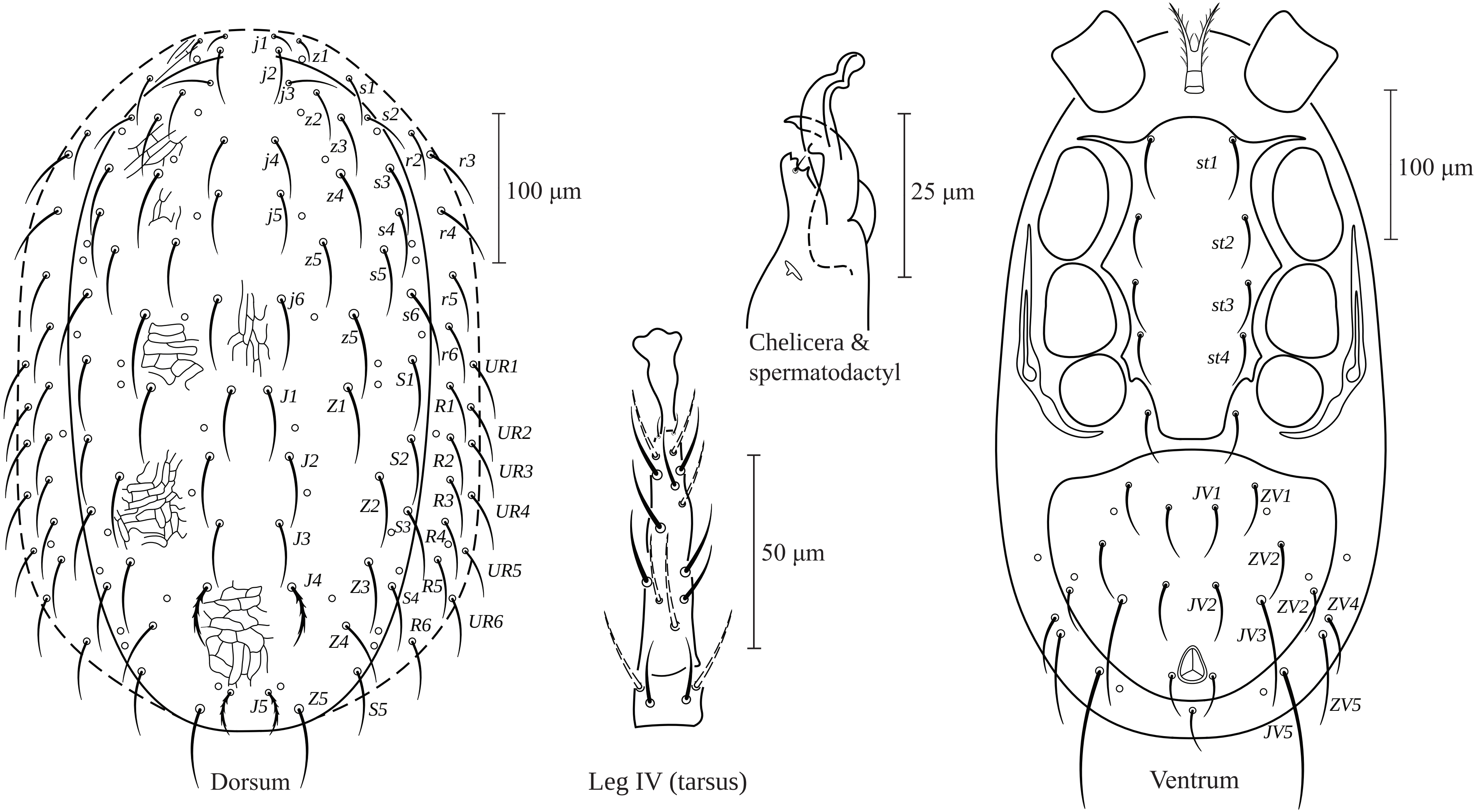
- One female specimen from Kasaragod (Supplyco district depot, 12° 30' 10" N, 74° 59' 20" E), collected from stored raw rice on 09 February 2021 by Neeraj Martin.
- Two female specimen from Kannur (Food Corporation of India Warehouse- Payyannur, 12° 05' 02.52" N, 75° 11' 58.56" E), collected from stored boiled rice on 16 July 2021 by Neeraj Martin.
- One female specimen from Kasargod (State warehousing corporation- Kanhangad, 12° 18' 36" N, 75° 5' 30" E), collected from stored basmati rice on 04 August 2021 by Neeraj Martin.
- One female specimen from Kannur (Supplyco Depot Warehouse- Thalipparamba, 12° 02' 28.34" N, 75° 21' 21.52" E), collected from stored coriander on 28 September 2021 by Neeraj Martin.
- One female specimen from Malappuram (Food Corporation of India- Kuttippuram, 10° 50' 42.00" N, 76° 02' 04.76" E), collected from stored wheat on 07 October 2021 by Neeraj Martin.
- One female specimen from Malappuram (Food Corporation of India- Angadippuram, 10°58'55.4"N 76°12'34.3"E), collected from stored boiled rice on 07 October 2021 by Neeraj Martin.
- One female specimen from Palakkad (Food Corporation of India- Puthuppariyaram, 10° 48' 28.63" N, 76° 37' 44.74" E), collected from stored boiled rice on 27 July 2022 by Neeraj Martin.
- One female specimen from Palakkad (Supplyco Taluk Depot- Kalvakulam, 10° 46' 25.51" N, 76° 40' 02.66" E), collected from stored cumin seeds on 27 July 2022 by Neeraj Martin.
- One female specimen from Malappuram (Supplyco supermarket- Manjeri, 11° 07' 14.93" N, 76° 07' 10.52" E), collected from stored chickpea on 25 February 2023 by Neeraj Martin.

PLATE 9 A



Blattisocius keegani **Fox, 1947, Adult female**

PLATE 9 B



***Blattisocius keegani* Fox, 1947, Adult male**

Blattisocius tarsalis (Berlese, 1918)

PLATE 10

Lasioseius (*Lasioseius*) *tarsalis* Berlese, 1918: 134.

Melichares (*Blattisocius*) *tarsalis* Evans, 1958: 209; Athias-Henriot, 1959: 162; Hughes, 1961: 235.

Blattisocius tarsalis Schweizer, 1961: 132; Chant, 1963: 298-300; Lindquist and Evans, 1965: 48; McGraw and Farrier, 1969: 59; Hughes, 1976: 325; Haines, 1979: 20; Domrow, 1979: 98; Halliday et al., 1998: 19; Bhattacharyya and Sanyal, 2002a: 171; Gupta, 2003: 3; Christian and Karg, 2006: 239; Gwiazdowicz, 2007: 66; Zhang and Fan, 2010: 283; Britto et al., 2012: 50; Moraes et al., 2016: 135.

Melichares tarsalis Hirschmann, 1962: 30.

Seiulus muricatus Burkhardt, 1920: 54 and Hase, 1928: 271.

Typhlodromus tineivorans Hughes, 1948: 144.

Blattisocius tineivorus Nesbitt, 1951: 51; Womersley, 1954: 184.

Blattisocius triodons Keegan, 1944: 181.

Blattisocius triodons Athias-Henriot, 1957: 333.

Lasioseius similis Schweizer, 1949: 49.

Garmania similis Westerboer, 1963: 278.

Blattisocius similis Christian and Karg, 2006: 239.

Diagnosis

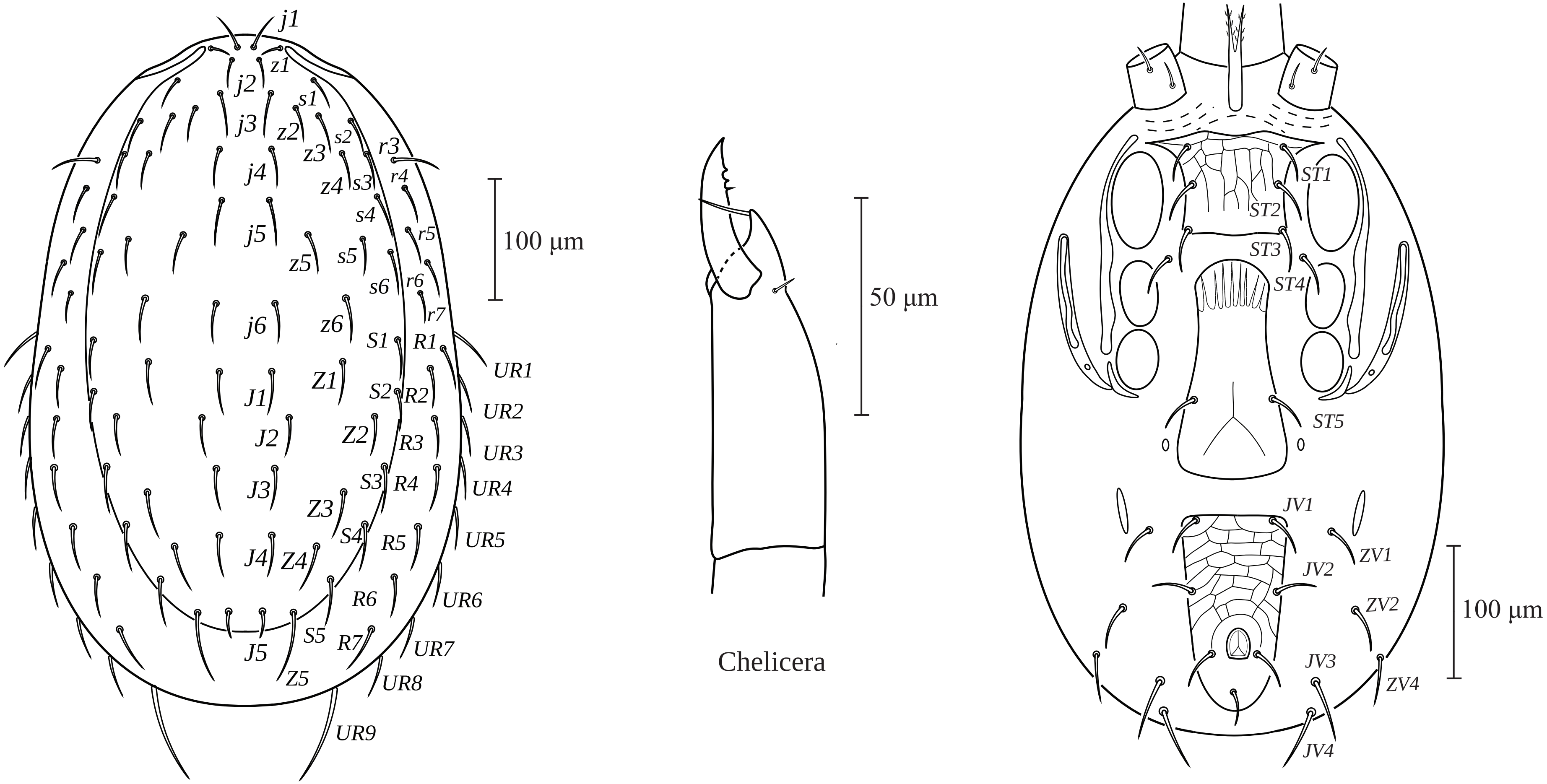
Female: Mean size of idiosoma: 520 x 328 µm. Tectum smoothly arched, featuring slender and convergent corniculi. Cheliceral fixed digit, edentate and truncate, distinctly shorter than the movable digit, terminates in a pilus dentilis, while the movable digit bears three diminutive teeth. Dorsal shield extending partially over the dorsal idiosomal surface, delicately reticulated carries 33 pairs of setae, including 15 pairs, arising from the posterior region of the shield. Five pairs of marginal setae (*r3* to *r7*) arise laterally and external to the anterior segment of the dorsal shield, accompanied by seven pairs (*R1* to *R7*) similarly positioned in the posterior region. Sternal shield faintly reticulated, possesses three pairs of setae, with metasternal setae situated on the interscutal membrane. Genital shield features one pair of setae. Anal shield oblong in outline, carries three pairs of setae in addition to the anal setae. Peritreme, reduced in length, extends anteriorly, reaching only to the posterior margin of coxa II, with the peritrematal plate closely adjoining the exopodal shield posteriorly. Spermatheca globular in appearance, includes a sinuous duct opening with its aperture positioned between coxae III and IV. Tarsi of the legs exhibit a pronounced darker pigmentation.

Male: Not obtained.

Material examined:

- One female specimen from Wayanad (Spice store- Mananthavady, 11° 45' 7" N, 76° 0' 33" E), collected from stored pepper on 16 April 2019 by Neeraj Martin.
- Two female specimens from Wayanad (Spice store- Meppadi, 11° 33' 24.5" N, 76° 07' 53.23" E), collected from stored pepper and pumpkin seeds on 16 April 2019 by Neeraj Martin.
- Two female specimens from Malappuram (Food Corporation of India Warehouse- Kuttippuram, 10° 50' 42.00" N, 76° 02' 04.76" E), collected from stored wheat on 07 October 2021 by Neeraj Martin.
- One female specimen from Malappuram (Supermarket- Manjeri, 11° 06' 35.83" N, 76° 07' 15.03" E), collected from stored broken brown rice on 26 November 2021 by Neeraj Martin.
- One female specimen from Malappuram (Warehouse- Parappanangadi, 11° 03' 03.25" N, 75° 51' 24.21" E), collected from stored wheat semolina on 10 June 2022 by Neeraj Martin.
- Two female specimens from Palakkad (Food Corporation of India- Puthuppariyaram 10° 48' 28.63" N, 76° 37' 44.74" E), collected from stored boiled rice on 27 July 2022 by Neeraj Martin.

PLATE 10



Dorsum Chelicera Ventrum

Blattisocius tarsalis **(Berlese, 1918), Adult female**

Genus *Hoploseius* Berlese, 1914

Hoploseius Berlese, 1914: 136; Vitzthum, 1941 765; Lindquist, 1963: 1176; 1964: 222; Westerboer, 1963: 190; Lindquist and Evans, 1965: 49; Farrier and Hennessey, 1993: 34; Karg, 1993: 246; Gwiazdowicz, 2007: 73; Gwiazdowicz et al., 2008: 36; Lindquist and Moraza, 2010: 3; Moraza and Lindquist, 2011: 3; Moraes et al., 2016: 39.

Lasioseius (Criniacus) Karg, 1980: 346; Naeem et al., 1985: 352; Christian and Karg, 2006: 106.

Diagnosis: Hypostomal seta *h2* typically not elongated than *h1*, *h3* and palpcoxal seta. Female cheliceral digits comparable in length, robust. Fixed digit apically features 3-8 horizontally aligned teeth, accompanied by 4-14 vertically aligned teeth. Movable digit usually tridentate (exceptionally unidentate, excluding apical tooth). Fixed cheliceral digit of males bears 10-11 teeth, excluding apical tooth and possess setiform pilus dentilis. Movable digit bidentate, including apical tooth. Spermatodactyl exhibits variability in shape, from nearly straight to ventrally curved and features broad, inflated extremity; subequal in length to movable digit. Oval shaped idiosoma; dorsal shield adorned with reticulate pattern; all dorsal setae smooth and acicular. Podonotum provided with 16-23 pairs of setae, including horizontally oriented *r3*. Opisthonotum typically possess 15 pairs of setae; 1-7 pairs of lateral setae present. Dorsal and lateral idiosomal setae prominently shortened, except for posterior-most setae, which may exhibit pronounced elongation. Posterior margin of genital shield truncate, bears *st5*. Female opisthogaster possess eight to ten pairs of setae (six pairs in males), excluding circumanal setae. In females, anterior portion of endopodal shield coalesced with sternal shield; posterior portion reduced to a narrow, elongate, wedge-shaped platelet positioned between coxae III-IV. Male peritrematic shield coalesced with exopodal shield, abutting coxa IV and endopodal shield coalesced with sternigenital shield. Leg chaetotaxy I–IV, genu: 11-11-9-9; tibia: 11-10-8-10. Leg II significantly stout, bears robust, spinose setae ventrally distributed from femur to tarsus. Leg III inconsistently feature ventral spine-shaped setae on certain segments.

Type species: *Lasioseius drosophili* Chant, 1963.

Hoploseius andamanensis Bhattacharyya, 2002

PLATE 11

Hoploseius andamanensis Bhattacharyya, 2002: 63.

Hoploseius andamanensis Mašán and Walter, 2004: 532; Moraes et al., 2016:157.

Hoploseius andamensis Faraji et al., 2006: 73.

Diagnosis

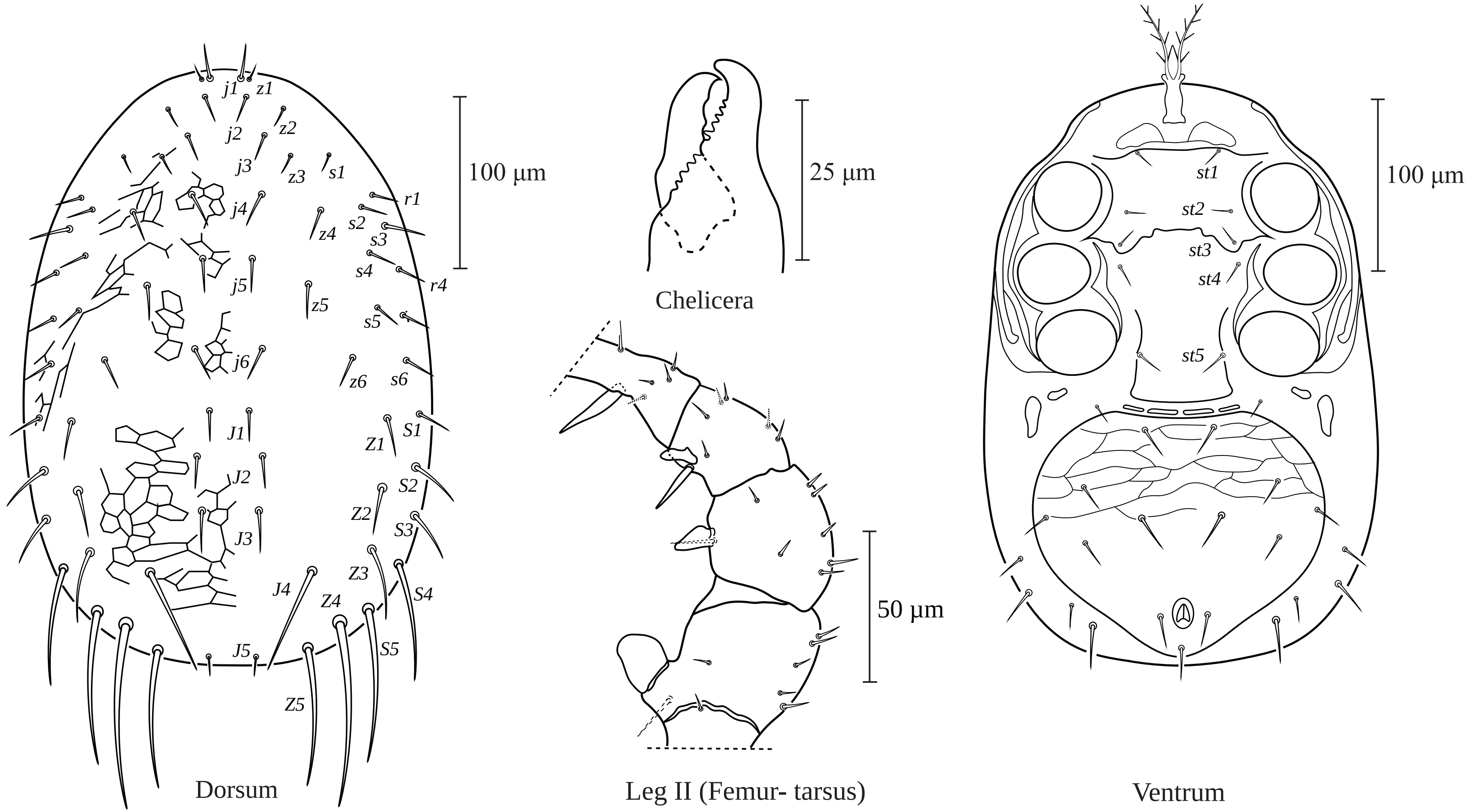
Female: Mean size of idiosoma: 333 x 216 µm. Fixed digit of chelicera features a serrated edge comprises a row of twelve sharp teeth. Movable digit with three broad, undulate teeth excluding the sharp apical tooth. Dorsal shield adorned with reticulations, enveloping the total area; featuring 36 pairs of simple setae, among which 21 pairs positioned on the podonotal region and 15 pairs placed on the opisthonotal region. Among the opisthonotal *Z*-series, setae *Z4* most elongated and positioned laterally. Opisthontal setae comprising *J4*, *Z3-Z5*, *S4* and *S5* exhibit a prominent increase in length compared to the remaining dorsal setae. Tritosternal laciniae intermediately pilose. Pre-endopodal plates positioned anterior to the sternal shield. Sternal shield displays inward indentation posteriorly, bearing *st1*-st3; *st4* located on the metasternal shield. Post-genital region composed of four well-demarcated sclerites. Two pairs of metapodal shields situated either side of the ventri-anal shield anteriorly in close proximity. Ventri-anal shield ornamented with delicate reticulations; comprises five pairs of ventral setae, two para-anal setae, and a single post-anal seta, placed posteriorly. Peritreme slender, terminates near the midpoint of coxa I. Exopodal shield fuse peritrematal shield at posterior end. Setae on the femur, genu, tibia, and tarsus of leg II exhibit modified shapes, comprising ensiform, spiniform, dolabriform, and obclavate morphologies. Legs I-IV terminates with ambulacra and claws.

Male: Not obtained

Material examined:

- Three female specimen from Malappuram (Nilambur, 11° 16' 27" N, 76° 14' 6" E), collected from Dried oyster mushroom on 22 April 2022 by Neeraj Martin.

PLATE 11



***Hoploseius andamanensis* Bhattacharyya, 2002, Adult female**

4.2.3.3. Family Melicharidae Hirschmann, 1962

Gamasidae Leach, 1815: 396; Hirschmann, 1962: 38.

Ascainae Voigts and Oudemans, 1905: 237; Vitzthum, 1929: 30; Bernhard, 1963: 33.

Phytoseiinae Berlese, 1916: 33.

Phytoseiidae Nesbitt, 1951: 1; Baker and Wharton, 1952: 88.

Laelaptidae Vitzthum, 1941:762; Baker and Wharton, 1952: 93.

Laelapidae Nesbitt, 1951: 1.

Aceosejidae Baker and Wharton, 1952: 58; Evans, 1957: 224; Hughes, 1961: 224; Krantz, 1962: 4; Athias-Henriot, 1968: 232; Bregetova, 1977: 169.

Aceosejinae Evans, 1957: 226; 1963: 302; Karg, 1962: 35; Krantz, 1962: 4.

Ameroseiidae Hughes, 1961: 244; Karg, 1976: 508; 1993: 220.

Melicharinae Hirschmann, 1962: 38.

Blattisociinae Chant, 1963: 243; Lindquist, 1964: 74.

Blattisociidae Lindquist, 1964: 68.

Ascidae Lindquist and Evans, 1965: 5; Zaher, 1986: 39; Farrier and Hennessey, 1993: 22; Halliday et al., 1998: 1.

Ascinae Lindquist and Evans, 1965: 38; Zaher, 1986: 49.

Melicharini Lindquist and Evans, 1965: 51.

Melicharidae Lindquist et al., 2009: 164; Moraes et al., 2016; 11, 198.

Diagnosis: Movable and fixed digits of chelicera subequal in length; fixed digit of bears 1-20 teeth in females and 1-12 teeth in males, excluding the apical tooth in both sexes. An inflated hyaline lobe, instead of a setiform pilus dentilis, occurs on the fixed digit, and positioned opposite the central line. In some *Proctolaelaps,* a dorsal and distally pointed process found instead of hyaline lobe. Movable digit carries up to three teeth, featuring a ventral mucro positioned near the base. Length of spermatodactyl variable; comparable to, or slightly exceeding the length of movable digit. Hypostomal setae *h3* usually exceeding *h1*, *h2*, and palpcoxal setae in length. Corniculi up to four times as long as proximal width, reaching up to six times in some *Proctolaelaps*. Tarsal apotele of pedipalps typically bifurcated, rarely trifurcated. Idiosoma oblong to oval shaped, featuring coalesced dorsal podonotal and opisthonotal shields; with or without prominent lateral notches at junction. Shields typically smooth or feature reticulations. Podonotum, encompassing the podonotal shield, generally comprises 14 to 23 pairs of setae. Opisthonotum complemented with 10 to 22 pairs of setae. Sternal seta *st*4 and lyrifissures *iv*3 positioned on either the metasternal plates or the integument. Setae *st*3 of males inserted external to the sternal shield. 0 to 16 pairs of setae inserted on the lateral unsclerotized integument, with or without posterior submarginal row of setae. Opisthogaster bears 6 to 12 pairs of setae. Endopodal shield coalesced with sternal shield only at anterior end. Exopodal shield defined or obscure between coxae II and IV. Peritreme stretches from stigma to near proximity of *s2*. Chaetotaxy of legs I–IV, genu: 13, 11, 9, 9; tibia: 13, 10, 8, 10. All legs bear pretarsi. Pulvilli of legs II-IV with rounded median section. In males, modified setae present on the ventral surface of certain segments.

Type genus: *Melichares* Hering, 1838

Genus *Proctolaelaps* Berlese, 1923

Proctolaelaps Berlese, 1923: 255; Evans, 1958: 197; Hughes, 1961: 227; Chant, 1963: 258; Lindquist and Evans, 1965: 53; Hughes, 1976: 317; Fain et al., 1977: 115; Evans and Till, 1979: 198; Karg, 1985: 187; Zaher, 1986: 59; OConnor et al., 1991: 348; Halliday et al., 1998: 28; Gupta, 2003: 8; Gwiazdowicz et al., 2008a: 31: Moraes et al., 2016: 52.

Chamolaelaps Turk and Turk, 1952: 482.

Blattilaelaps Womersley, 1956: 566.

Garmania (*Garmania*) Westerboer, 1963: 343.

Garmaniella Karg, 1971: 225; 2005: 63.

Diagnosis: Hypostomal setae *h1* prominently stouter, longer than other hypostomatal and palpcoxal setae. Movable cheliceral digit features 6-15 teeth in females and 0-1 teeth in males, excluding apical tooth. Fixed digit of chelicera bears 1-20 teeth in females and 1-12 teeth in males. Length of spermatodactyl variable, comparable to or slightly exceeding movable digit, with distal tapering. Palp tarsal apotele bifurcated; rarely trifurcated. Idiosoma oval shaped; podonotal and opisthonotal shields coalesced, devoid of lateral incision at the merging point. Dorsal shields smooth or ornamented. Podonotum normally features 23 pairs of setae. Marginal prodorsal setae *r3* aligned in an upright position relative to dorsal shield edge. Opisthonotal shield bears 18-22 pairs of setae. Typically, 0-3 pairs of posterior sub marginal row of setae present. Dorsal and lateral idiosomal setae comparable in length, predominantly smooth and acicular. Female endopodal shield coalesced with sternal shield anteriorly. Male endopodal shield completely integrated with sternogenital shield. Peritreme extends from stigma to the close proximity of *z1*. Spermathecal apparatus tubular, narrow or cornuted. Leg chaetotaxy: Leg I: genu 13 (exceptionally 12), tibia 13; Leg II: genu 11, tibia 10; Leg III: genu 9 (rarely 7-8), tibia 8 (rarely 9); Leg IV: genu 9, tibia 10 (rarely 9). Leg II of males prominently robust than other legs. Macrosetae absent or rarely present (1-2 on leg IV). Legs I-IV of males inconsistently bear modified, spine-like setae.

Type species: *Proctolaelaps productus* Berlese, 1923

Proctolaelaps bickleyi (Bram, 1956)

PLATE 12

Garmania bickleyi Bram, 1956: 292.

Proctolaelaps bickleyi Athias-Henriot 1959: 171; Chant 1963: 269; Lindquist and Evans 1965: 60; Lindquist and Hunter 1965: 16; McGraw and Farrier 1969: 72; Treat 1975: 130; Bregetova 1977: 217; Farrier and Hennessey 1993: 42; Ostovan and Kamali 1994: 11; 1997: 30; Halliday *et al*. 1998: 31; Kamali *et al*. 2001: 8; Faraji *et al*. 2007: 111; Moraes *et al*. 2016: 206.

Proctolaelaps (*Proctolaelaps*) *bickleyi* Karg 1985: 192; 1988a: 448.

Garmania (*Garmania*) *striata* Westerboer, 1963: 356; Karg 1985:192; 1988a: 448; Farrier and Hennessey 1993: 42; Halliday *et al*. 1998: 31.

Proctolaelaps striatus Karg 1971: 241; 1993: 237.

Diagnosis

Female: Mean size of idiosoma: 423 x 307 µm. Fixed digit of chelicera bears 14 to 15 conspicuous, sharp teeth; movable digit equipped with 3 teeth. Palp tarsal apotele two pronged. Epistome exhibits a variable morphology, appearing as either arcuate or subtriangular in shape, and features a serrated margin. Dorsal idiosoma features 44 pairs of acicular setae including setae *r2-r6* and *R1-R6*. Opisthonotal setae *Z5* conspicuously elongated, compared to the remaining dorsal setae. Dorsal shield ornamented with horizontally elongated reticulations, with an undulate appearance; complemented with 18 pairs of pores. Podonotal area of dorsal shield exhibits a glabrous area confined within setae *j3* to *j6*. Tritosternal laciniae bifurcated. Sternal shield coalesces with the anterior part of endopodal plate. Genital shield adorned with longitudinally elongated reticulations and bear an anterior hyaline extension. Anal plate exhibits a slight anterior protrusion. Ventral setae *JV5* distinctly elongated.

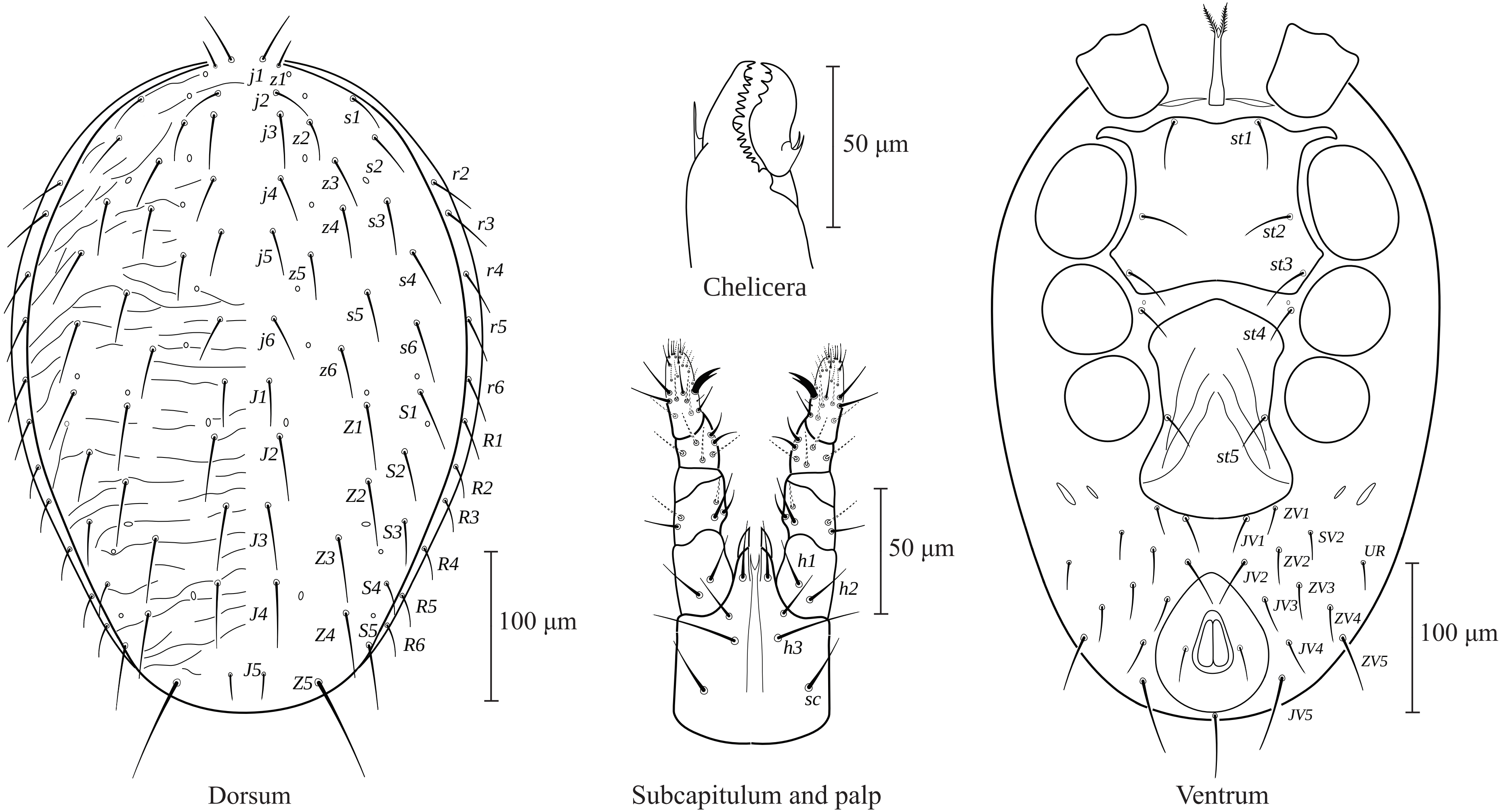
Male: Not obtained

Material examined:

- One female specimen from Kozhikode (Market Grocery store, 11° 14' 59" N, 75° 46' 36" E), collected from stored fennel seeds on 27 September 2019 by Neeraj Martin.

- Two female specimen from Wayanad (Supplyco Depot Warehouse- Kalpetta, 11°37'36.2"N 76°04'15.3"E), collected from stored black gram on 06 January 2021 by Neeraj Martin.
- One female specimen from Kannur (Supplyco Depot Warehouse-Thalipparamba, 12° 02' 28.34" N, 75° 21' 21.52" E), collected from stored boiled rice on 28 September 2021 by Neeraj Martin.
- One female specimen from Malappuram (Makkaraparamba, 11° 01' 00.20" N, 76° 07' 26.15" E), collected from stored fenugreek on 22 April 2022 by Neeraj Martin.

PLATE 12



***Proctolaelaps bickleyi* (Bram, 1956), Adult female**

Proctolaelaps pygmaeus (Müller, 1859)

PLATE 13

Gamasus pygmaeus Müller, 1859: 30.

Holostaspis pygmaea Müller, 1860: 51.

Haemolaelaps pygmaeus Wolf, 1934: 644.

Proctolaelaps pygmaeus Chant, 1963: 259; Ehara, 1964: 387; McGraw and Farrier, 1969: 90; Bregetova, 1977: 213; Zaher, 1986: 61; Jordaan and Loots, 1987: 53; Halliday et al., 1998: 37; Gupta, 2003: 8; Faraji, 2011: 26; Moraes et al., 2016: 223.

Proctolaelaps (*Proctolaelaps*) *pygmaeus* Ryke, 1964: 341; Karg, 1985: 190; Karg, 1988a: 447.

Hypoaspis hypudaei Oudemans, 1902a: 21; Athias-Henriot, 1961: 451; Ryke, 1964: 341; Karg, 1985: 191; Zaher, 1986: 61; Farrier and Hennessey, 1993: 45.

Garmania (*Garmania*) *hypudaei* Westerboer, 1963: 360.

Lasioseius salisburgensis Gwiazdowicz et al., 2008a: 33.

Proctolaelaps innumerabilis Christian and Karg, 2006: 238

Hypoaspis ovatus Ma, 2006: 24.

Diagnosis

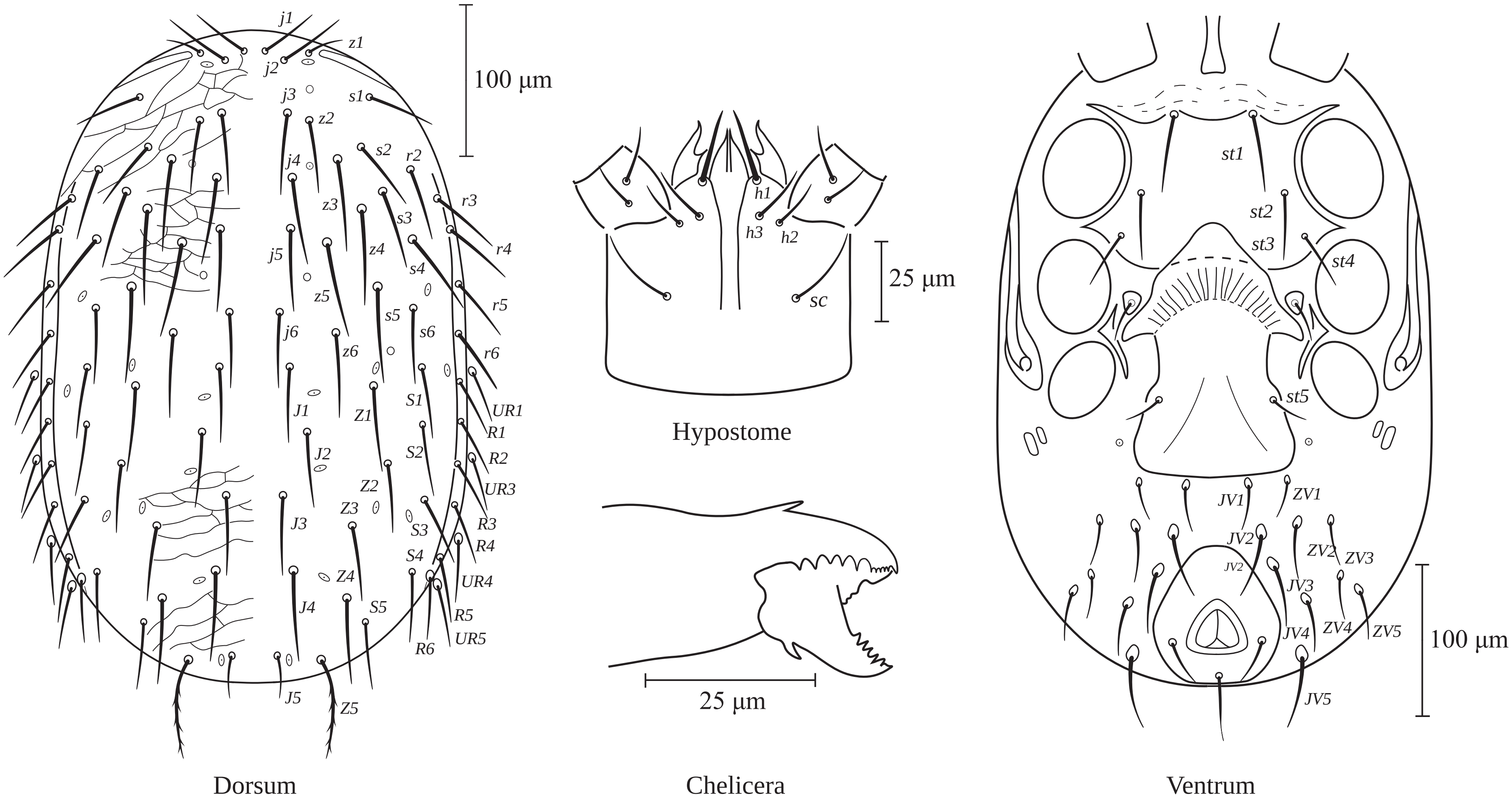
Female: Mean size of idiosoma: 424 x 277 µm. Fixed digit of chelicera features five large, robust teeth, positioned proximally, followed by five diminutive teeth linearly aligned and subterminally placed. Movable digit possesses three teeth; smallest teeth occur proximally. Hypostomal setae *h1* significantly thicker and more robust in comparison to *h2*, *h3*, and *sc*. Podonotal area of dorsal shield adorned with stretched reticulations; complemented with 23 pairs of setae, comprising five pairs of marginal prodorsal setae (*r2-r6*), in addition to six setae each from *j*, *z*, and *s* series. Two pairs of conspicuous pores present; one positioned in close proximity to setae *j4*, second pair interposed between *j5* and *j6*. Opisthonotum ornamented with horizontally stretched reticulations; features 21 pairs of opisthonotal setae, comprising 5 setae each from *J*, *Z*, and *S* series, along with six setae from *R* series; seta *R6* variably placed, occurring either on or off the shield. Setae located on dorsal shield predominantly acicular, consistent in size and form; setae *Z5* deviate from this pattern, featuring barbs along the length of shaft. Lateral membranous integument bears four pairs of acicular, posterior submarginal setae, positioned on individual diminutive sclerites. Genital shield lacks striae or reticulations, exhibits an anterior hyaline extension; lateral margins bear a protruding prominence, accompanied by a slight arcuate posterior margin. Peritrematic shield coalesces with dorsal shield at the level of setae *s2*

Male: Not obtained.

Material examined:

- Two female specimen from Kozhikode (Supplyco Depot Warehouse- Thamarassery, 11° 23' 26" N, 75° 55' 18" E), collected from stored mustard on 12 February 2019 by Neeraj Martin.
- Two female specimen from Kasaragod (Thrikaripur, 12° 8' 40" N, 75° 10' 15" E), collected from stored raisins on 22 August 2019 by Neeraj Martin.
- Two female specimen from Kozhikode (Food Corporation of India Warehouse- Thikkodi, 11° 29' 40" N, 75° 37' 34" E), collected from stored wheat on 17 May 2019 by Neeraj Martin.
- Two female specimen from Malappuram (State warehousing Corporation- Manjeri, 11° 08' 04.16" N, 76° 06' 51.41" E), collected from stored boiled rice on 22 April 2022 by Neeraj Martin.

PLATE 13



***Proctolaelaps pygmaeus* (Müller, 1859), Adult female**

4.2.3.4. Family Phytoseiidae Berlese, 1916

Phytoseiini Berlese, 1916: 3.

Phytoseiinae Vitzthum, 1941: 768.

Phytoseiidae Baker and Wharton, 1952: 87; Muma, 1961: 270; Chant, 1965: 353; Muma and Denmark, 1970: 11; Tuttle and Muma, 1973: 4; Chaudhri et al., 1974: 204; Chant et al., 1978: 1330; Karg, 1982: 207; Gupta, 1986: 350; Takahashi and Chant, 1993: 16; Yoshida-Shaul and Chant, 1995: 5; Gupta and Chatterjee, 1997: 524; Chant and McMurtry, 2007: 219; Barbar, 2013: 249; Demite et al., 2014: 571; Tsolakis and Ragusa, 2015: 229.

***Diagnosis*:** Movable digit of chelicera edentate or dentate; fixed digit features a variable number of teeth; bears a pilus dentilis. Male movable digit possesses a spermatophoral process. Palp apotele bifurcated. Tectum smooth or moderately serrated. Dorsal shield intact or transversely partitioned, featuring 23 or fewer pairs of setae, comprising marginal setae *r3* and *R1*, along with 1-3 pairs of sublateral setae. Coxal plates coalesced to compose the sternal shield; variably sclerotized and textured. Typically, bears 3 pairs of sternal setae; occasionally 2 pairs, with *st*3 positioned on integument. Sternigenital shield in males features 5 pairs of setae. Ventrianal shield of males equipped with 4-5 pairs of setae; exhibiting varying level of integrity, ranging from entire to fragmented, with occasional fusion to the sternitigenital shield. A pair of setae present on the posteriorly truncated genital shield. A single pair of spermathecae positioned between coxae III- IV. Female ventrianal shield elongated, variable in shape from square to pentagonal, and carries 1 to 7 pairs of preanal setae in addition to para and postanal setae. Setae *JV5* present, exhibiting variable forms; smooth, serrated or barbed. Male genital aperture positioned on anterior sternigenital shield. In certain species, peritrematal plate coalesce anteriorly with dorsal shield and recurves posteriorly around coxae IV. Chaetotaxy of legs II and III variable among genera. Seven setae consistently observed on genua II-IV in *Amblyseius*. Genu, tibia, and basitarsus IV possess macrosetae; variable in shape, appearing capitate, spatulated or simple. All legs provided with pretarsus and ambulacra.

Type Genus: *Phytoseius* Ribaga, 1904

Genus *Amblyseius* Berlese, 1914

Amblyseius Berlese, 1914: 143: Gupta, 1985: 333; Papadoulis and Emmanouel, 1991: 35; Chant and McMurtry, 2007: 73.

Amblyseiapsis Garman, 1948: 17.

Kampimodromus Nesbitt 1951: 52.

Typhlodromus (*Typhlodromopsis*) De Leon, 1959: 113.

Amblyseius (*Amblyseialus*) Muma, 1961: 287.

Chelaseius Muma and Denmark, 1968: 232.

Athlaseius Wainstein, 1962: 17.

Amblyseialus Muma, 1965: 245.

Quadromalus Moraes et al., 1982: 15-17.

Propriaseiapsis (*Pelaiseius*) Karg, 1983: 303.

Amblyseius (*Multiseius*) Denmark and Muma, 1989: 82.

Amblyseius (*Pauciseius*) Denmark and Muma, 1989: 132.

***Diagnosis*:** Cheliceral fixed generally bears multiple denticles. Dorsal idiosomal shield bearing 13 to 19 pairs of setae. All species exhibit reduced or minute *z2*, *z4*, *Z1*, *S2*, *S4*, and *S5* setae, comparable in length (except *A. americanus*, *z4* elongated). Typically, setae *s4*, *Z4*, and *Z5* exceptionally elongated; few species exhibit deviations from this feature. Both dorsal and ventral shields smooth; dorsal shield exhibiting diminished or minimal level of sclerotization. Female ventrianal shield exhibits shape variability, ranging from pentagonal (more frequently occurring shape) to pyriform shapes or features distinctly demarcated ventral and anal shields. In some species, the anal shield may be reduced, bearing fewer than three pairs of preanal setae. Legs I-III possess macrosetae. Tarsus I usually features a protruding upright seta, positioned proximally, along with a distinct macroseta inserted on genu I. Males typically possess three pairs of preanal setae distributed in a triangular pattern. Presence of third caudoventral seta (*ZV3*) inconsistent among species, being either present or absent; when present, it exhibits intraspecific variability.

Type species: *Zercon abtusus* Koch, 1839.

Amblyseius indirae Gupta, 1985

PLATE 14

Amblyseius (*Amblyseius*) *indirae* Gupta, 1985: 209-214.

Diagnosis

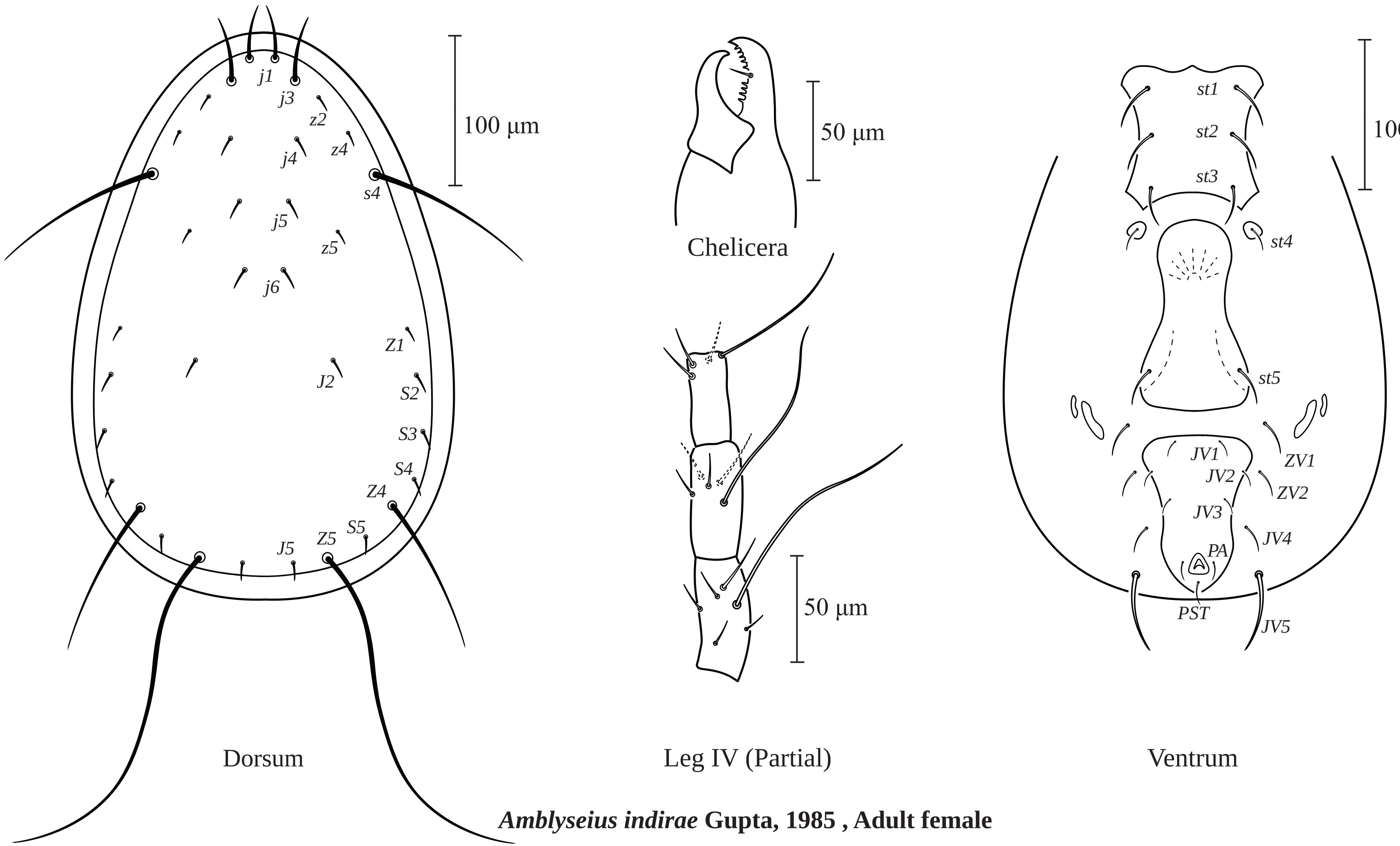
Female: Mean size of idiosoma: 384x280 µm. Cheliceral fixed digit bears four teeth anteriad to the setiform pilus dentilis and five teeth posteriad to it, movable digit edentate. The dorsal shield bears 17 pairs of setae, comprising conspicuously elongated dorsal setae *j1*, *j3*, *s4*, *Z4*, and *Z5*, of which *Z5* exceptionally long, the remaining 12 pairs persist reduced and diminutive. Sternal shield encompassing three pairs of sternal setae (*st1-3*) and features an indentation posterior to *st3*. Metasternal shield small, compact, and well-defined, bearing seta *st4*, and the genital shield possesses a pair of setae, *st5*. Ventrianal shield exhibits a cyathiform outline, bearing three pairs of preanal setae and a pair of preanal pores. Lateral margins of the ventrianal shield display an inward recession anterior to the ventrianal pores. Ventrianal shield encircled by four pairs of setae. Two pairs of metapodal plates present, comprising a prominent, slender, elongate pair and a small supplementary pair situated anterolaterally. Peritreme reaches anteriorly beyond the insertion point of seta *j1*. Spermatheca exhibits a cervix with a slight flare and a saccular morphology, atrium remains undifferentiated. Leg IV equipped with macrosetae.

Male: Not obtained.

Material Examined:

- Two female specimen from Wayanad (Mananthavady, 11° 45' 7'' N, 76° 0' 33'' E), collected from stored pepper on 16 April 2019 by Neeraj Martin.
- One female specimen from Wayanad (State Warehousing Corporation- Kalpetta, 11° 36' 53'' N, 76° 4' 25'' E), collected from stored pepper on 16 January 2021 by Neeraj Martin.

PLATE 14



Amblyseius indirae **Gupta, 1985 , Adult female**

4.2.3.5. Family Sejidae Berlese, 1913

Sejidae Koch, 1836: 117; Berlese, 1905: 162; Lindquist and Evans, 1965: 48; Hirschmann, 1991: 109; Hirschmann et al., 1991: 141; Lekveishvili and Krantz, 2004: 2; Lekveishvili and Klompen, 2006: 2323.

Diagnosis**:** Hypostome usually features profusely expanded anterior hypostomal setae (*h1*), which appear as membranous lobular structures (except *Sejus krantzi*, *h1* setiform and less expanded). Fixed and movable digit of chelicera bear numerous sharp teeth. Ventral idiosoma devoid of metapodal plates in both males and females. Female sternal platelets (*st1*) when present, typically remain divided, neither coalesce to each other nor to *st*2 bearing platelets. Prominent, posterior opisthonotal cornulate protrusions bearing elongated setae, consistently present across all instars in most species, with occasional exceptions; these protrusions may disappear during the protonymphal or deutonymphal stages in certain species. Proximal/ basal border of female genital shield positioned co-linear with posterior extremity of coxae IV. Length of female genital shield slightly exceeding width; provided with one to six pairs of laterally positioned setae. Mesonotal and pygidial shields in females not coalesced, separate; lateral shields not developed. Leg I of males bears large spiniform setae; less prominent in females.

Type genus: *Sejus* C. L. Koch, 1936

Genus *Sejus* Koch, 1836

Sejus Koch, 1836; Lindquist and Evans, 1965: 50; Lekveishvili and Klompen, 2006: 2324. Babaeian and Gwiazdowicz, 2021: 1.

Liroaspis Banks, 1902: 212; Athias-Henriot, 1960: 160.

Willmannia Balogh, 1938; 262; Hirschmann, 1991: 124.

***Diagnosis*:** Hypostomal setae *h1* prominently inflated distally, appearing cudgel-like. Pedipalp apotele bifurcated. Palp genu possesses up to six setae. Fixed digit of chelicera features a row of 8-14 diminutive teeth and a distinct pilus dentilis. Spermatodactyl absent in males. Shape of idiosoma variable; elongated, elliptical or ovate, bearing prominent posterior ampulliform protuberance (excluding *S. sejiformis*). Morphology and number of dorsal shields inconsistent and vary according to sex or ontogenetic stage. Males bear distinct podonotal and opisthonotal shields. Deutonymphs and females typically possess a single podonotal shield, four scutellae, and a pygidial shield. Posterior mesonotal shields in females lack coalescence, existing as distinct entities. Sternal platelets carrying setae *st1* and *st2* remain separate in females. Sternal shield shortened but broad. Male genital aperture positioned on sternigenital shield, aligned with second coxal segment. Occasionally, ventrianal shield coalesce with pygidial shield. Peritrematal shields broad, confluent with podonotal shield at dorsal anterior extremity. Texture of both dorsal and ventral shields variable, exhibiting a range of sculptural features, including punctations, granulations, tubercles, verrucosity, or wart-like projections. Setal morphology includes simple, spatulate, pilose, bipectinate and serrate. Certain opisthonotal spatulate setae possess a distinctive, hyalinised apical sheath. Opisthonotal setae *J5* and *Z5* exhibits exceptional and pronounced elongation, differing markedly from other dorsal setae. Tarsus I incorporates an acrotarsal element. Tarsus IV comprises more than twenty setae, including *av4* and *pv4*, which positioned on distinctly demarcated intercalary sclerite. Legs of males devoid of apophysis-like structures.

Type species: *Sejus togatus* Koch, 1836

Sejus carolinensis Lekveishvili & Klompen, 2004

PLATE 15

Sejus carolinensis Lekveishvili and Klompen, 2004: 232.

Diagnosis

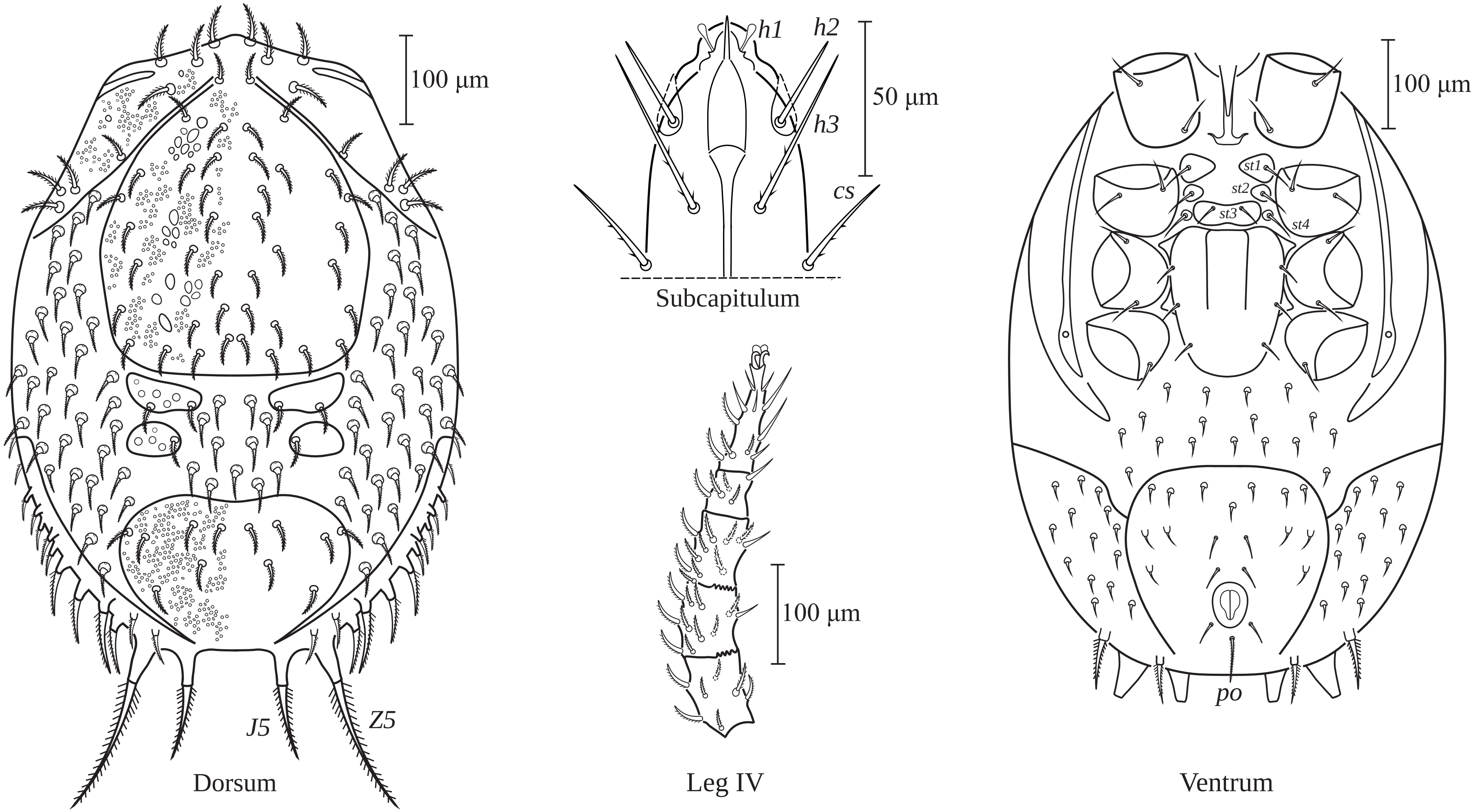
Female: Mean size of idiosoma: 692 x 498 µm. Deutosternum slender, retaining a consistent width for the majority of its length, widening distally in the final quarter, and carries eight rows of denticles. Gnathotectum features denticulated anterior margin. Hypostomal seta *h1* enlarged proximally, and tapering distally; *h3* spiculated. Movable digit of the chelicera comprises a single row of diminutive teeth, appearing as a serrated edge. Podonotal shield complemented with 20 pairs of spiculated setae. Posterior mesonotal shields bear one seta each. The cordate pygidial shield, features eight pairs of setae. 11 to 12 setae distributed intermediately between the mesonotal and pygidial shield. Posterior opisthonotal margin exhibits robust sclerotization, symmetrically carries approximately 13 setae. Posterior protrusions distinctly demarcated, and spaced, provided with markedly elongated, ciliated opisthonotal setae *J5* and *Z5*. All dorsal setae spiculated; setae embedded in the unsclerotized integument, arise from small tubercles. Proximal tritosternum exhibits anchor-shaped lateral protrusions. Sternal setae *st1* and *st2* positioned on separate, faintly demarcated platelets; *st4* inserted on diminutive, indistinctly defined platelets. Ventrianal shield oval in outline, possesses five pairs of setae and one unpaired seta; posteriorly confluent with the flanking, profusely sclerotized, postero-marginal shields. All ventral setae smooth and short, except for an elongated, spiculated seta *po*. Peritremes long, reaching to the level of coxa I.

Male: Not obtained

Material examined:

- Two female specimen from Kasaragod (Dry fruits store- Hosdurg, 12° 38' 34.82" N, 74° 55' 35.24" E), collected from stored walnut on 09 February 2021 by Neeraj Martin.

PLATE 15



Sejus carolinensis **Lekveishvili & Klompen, 2004, Adult female**

4.2.3.6. Family Cheyletidae Leach, 1815

Cheyletidae Leach, 1815: 399; Baker, 1949: 269; Dubinin, 1957: 71; Zaher and Soliman, 1967: 21; Volgin, 1969: 3; Summers and Price, 1970: 4; Gerson et al., 1999: 37; Bochkov and Fain, 2001: 7; Xia, 2010:159; Negm and Mesbah, 2014: 390.

***Diagnosis*:** Gnathosoma robust, well developed and comprises more than one-third of the idiosomal length in most predatory genera; relatively reduced in parasitic genera. Gnathosomal apex occasionally features median protuberances. Palp typically comprised of five segments. Palp tarsus well formed in predatory genera, shortened in some parasitic genera. Palpal claws variable in form; usually smooth and curved, may bear teeth or ridges proximally. Palp tibia features three filiform or thickened setae, positioned dorsally, ventrally, and laterally. Predatory species equipped with two dorsal comb-like setae, two ventral thickened setae, and one solenidion on palp tarsus. Idiosoma rhomboid or ovoid in shape, some genera feature elongated idiosoma, with different levels of opisthosomal reduction. Propodosoma and hysterosoma bears one or more dorsal shields. Dorsal setal morphology variable, comprising simple, serrate, clavate, lanceolate and spatulate forms. Chelicerae short with stylet-like appearance, specialized for piercing. Eyes lens-like, absent in parasitic forms and vestigial in some predatory species. Legs typically comprise five segments; length and structure variable among genera. Predatory species normally possess legs proportionate to idiosoma. Tarsi terminally equipped with a pair of claws.

Type genus: *Cheyletus* Latreille, 1796

Genus *Acaropsella* Volgin, 1962

Acaropsella, Volgin, 1989: 391; Summers and Price, 1970: 62; Gerson, 1967: 359; Koç, 1998: 195; Fain and Bochkov, 2001: 66; Akbar et al., 2008: 187.

Diagnosis**:** Female palp femora feature four setae; comprising one dorsal, one dorso-lateral, and two ventrally positioned setae. Palp genua equipped with one dorsal seta. Palp tarsus exhibits a short, stout solenidion along with four setae. Palp claws possess four to six dentiform processes positioned on the proximal half. Peritremes arcuate in shape, consists of 6-7 pairs of elongated segments. Idiosoma elongated, comprising one propodosomal and one hysterosomal plate. Eyes prominent, well formed. Hysterosomal plate exceeds propodosomal plate in length. Rostrum and idiosomal plates occasionally ornamented with reticulations. Position of hysterosomal setae *l1* variable, occurring either on or off hysterosomal plate. Ventrum devoid of plates. Genito-anal setae exhibit varying morphologies, comprising slender, hair-like and bifurcate forms. Setae on tibiae I-IV occasionally display a hair-like appearance. Tibia I features a short dorsal solenidion and bears five setae. Tibiae I and II complemented with one or two narrow, lanceolate setae. Dorsal setae on genua I-II slender or piliform. Tarsi I devoid of apical protuberance; solenidion *ω1* present, guard seta absent. Ventral surface of tarsus I bears two central setae. Claws on tarsus I diminutive; claws on tarsi II-IV distinctly elongated, smooth, and deprived of basal processes.

Type species: *Neoacaropsis rohdendorfi* Volgin, 1962

Acaropsella strioreticulata Martin and James 2023

PLATE 16 A, B

Acaropsella strioreticulata Martin and James, 2023: 61-66.

Description

Female: Gnathosoma: Length 125 (122-127) and width 81 (79-82). Rostral shield has coarse robust pentagonal or hexagonal reticulation pattern. Rostrum tappers to blunt end. Tegmen broader than protegmen. Palp femur have one spatulate dorsal setae of length 26 (25-26), two ventral setae and one dorsolateral seta. Transverse striations seen on palp femur. Palp tibia with one comb like seta with 13 teeth, two sickle like setae, palp claw with four teeth. Horse- shoe shaped peritremes with six links on each side.

Dorsal idiosoma: ovoid, length 360 (352-366) and width 250 (244-254). Two dorsal shields are separated by transverse striation membrane of 34 (33-35) width. Both shields have prominent coarse pentagonal or hexagonal reticulation pattern. All dorsal setae are broadly spatulate and barbed. Propodosomal shield length 149 (146-151), width 166 (162-169) and trapezoidal in shape. One pair of eyes present, placed off propodosomal shield. Propodosomal shield bear four pairs of lateral setae *vi* (25, 24-25), *ve* (31, 30-32), *sci* (29, 28-29) and *sce* (31, 30-32) and three pairs of median setae *d1* (26, 25-26), *d2* (26, 25-26) and *d3* (25, 24-25) inserted within the shield. Humeral setae of length 35(34-36) similar to dorsal setae and seen laterally positioned on the membrane and placed off the propodosomal shield. Hysterosomal shield of length 149(146-151) and width 166(162-169) features four pairs of lateral setae *l1* (31, 30-32), *l2* (31, 30- 32), *l3* (31, 30-32), *l4* (32, 31-33) and four pairs of median setae *d4* (26, 25-26), *d5* (26, 25-26), *d6* (26, 25-26) and *d7* (32, 31-33). Lateral seta *l5* (34, 33-35) placed caudally on membrane and excluded from the shield. Membranous area around the shield bears striations.

Ventral idiosoma: All setae in the genital region are acicular. Genital setae *g1* 14(14), *g2* 16 (16) and *g3* 16 (16). Anal setae *a1*: 16 (16), *a2*: 26 (25-26) and *a3*: 20 (20). The genito-anal region exhibits visible striations.

Legs: Length of leg I (from coxae to tip of tarsi): 228 (223-232), leg II: 195 (191-198), leg III: 206 (201-209) and IV: 275 (269-280). Ratio of leg I/ idiosoma= 0.63 (0.63- 0.65), leg II/ idiosoma =0.54 (0.52-0.54), leg III/ idiosoma = 0.57 (0.56-0.58) and leg IV / idiosoma= 0.76

(0.73-0.76). Length of solenidion *ω1* on tarsus I is 30 (29-30) µm and is supported by a small guard seta. Setae and solenidion in leg segments I-IV: coxae 2-1-2-2, trochanter 1-2-2-1, femur 2-2- 2-1, genu 2-2-2-2, tibia 6-4-4-4 and tarsi 11-8-7-5. All leg segments except tarsi I- IV have transverse striation whereas tarsi I-IV have longitudinal striation. Tarsal claws bear a terminal fork-like eupathidia.

Male: Not obtained

Material examined: Female holotype (ZSI/WGRC/I.R.INV.26089) and four female paratypes (ZSI/WGRC/I.R.INV.26090-26093) were collected from stored wheat semolina from Kozhikode district (11° 22' 3.54" N, 75° 47' 35.74" E) on 23 September 2021 by Neeraj Martin. The specimens were deposited at the Western Ghat Field Research Centre, Zoological Survey of India, Kozhikode, Kerala, India.

Remarks: *Acaropsella strioreticulata* exhibits close morphological resemblance to *A. kinshasensis* Fain, 1972 and *A. filipina* Corpuz-Raros, 1998. The species *A. filipina* and *A. konoi* are morphologically indistinguishable from *A. kinshasensis*. The diagnostic features highlighted by Corpuz-Raros (1988) and Tseng (1977) as distinctive, such as the reticulated stylophore and dorsal shields, along with the fan-shaped dorsal seta on the palpal femur, are also evident in *A. kinshasensis*. Subsequently, Fain and Bochkov (2001) synonymized *A. filipina* and *A. konoi* as junior synonyms of *A. kinshasensis*. *A. strioreticulata* shares several morphological traits with *A. kinshasensis*, including reticulation on the rostrum and idiosoma, a membranous separation between the propodosomal and idiosomal shields, a total of 16 dorsal setae with *l5* positioned off the shield, a comb seta bearing 13 processes, and simple acicular anal setae. However, *A. strioreticulata* distinctly differs from *A. kinshasensis* in possessing four palp teeth (compared to 5–6 in *A. kinshasensis*) and having propodosomal and hysterosomal shields of equal length (with a shield length ratio of 1 in *A. strioreticulata* versus 0.78 in *A. kinshasensis*). The hysterosomal shield is longer than the propodosomal shield in *A. kinshasensis*. Setal morphology further distinguishes the two species: in *A. kinshasensis*, all setae on tibia I are hair-like, whereas in *A. strioreticulata*, all tibia I setae are simple except for one thickened seta (an immature form of a fan-like seta). *A. kinshasensis* possesses a fan-like seta on tibia III, a feature absent in *A. strioreticulata*. Furthermore, *A. filipina* exhibits three sickle setae, while *A. strioreticulata* has only two. Chaetotaxy of femur I–IV in *A. strioreticulata* is 2-2-2-1, contrasting with 2-2-1-1 in *A. filipina*. The eyes in *A. strioreticulata* are positioned off the propodosomal shield, whereas in *A. filipina*, they are located within the antero-lateral margins of the propodosomal shield. Chaetotaxy of tarsi I–IV (including solenidion) is 11-8-7-5 in *A. strioreticulata* but 6-5-4-4 in *A. filipina*. A distinctive morphological feature of *A. strioreticulata* and *A. shaziai* is the transverse striation on all leg segments, except for the tarsi, which exhibit longitudinal striation. This characteristic is absent in other *Acaropsella* species. *A. strioreticulata* can be differentiated from *A. schmidtmanni*, *A. rohdendorfi*, and *A. volgini* by the presence of coarse, robust pentagonal or hexagonal reticulation on the rostral and idiosomal shields, a feature lacking in the latter three species. Additionally, *A. strioreticulata* possesses four palp teeth, distinguishing it from *A. nobilis* and *A. kulagini*, which have six palp teeth. Finally, *A. strioreticulata* differs from *A. shazai* and *A. walli* in the presence of 13 processes on the comb seta and the position of dorsal seta *l5* placed off the shield. In contrast, *A. shazai* and *A. walli* exhibit 16 processes on the comb seta and have dorsal setae *l1*, *l4*, and *l5* positioned off the shield.

Etymology: The specimen named after its morphological features.

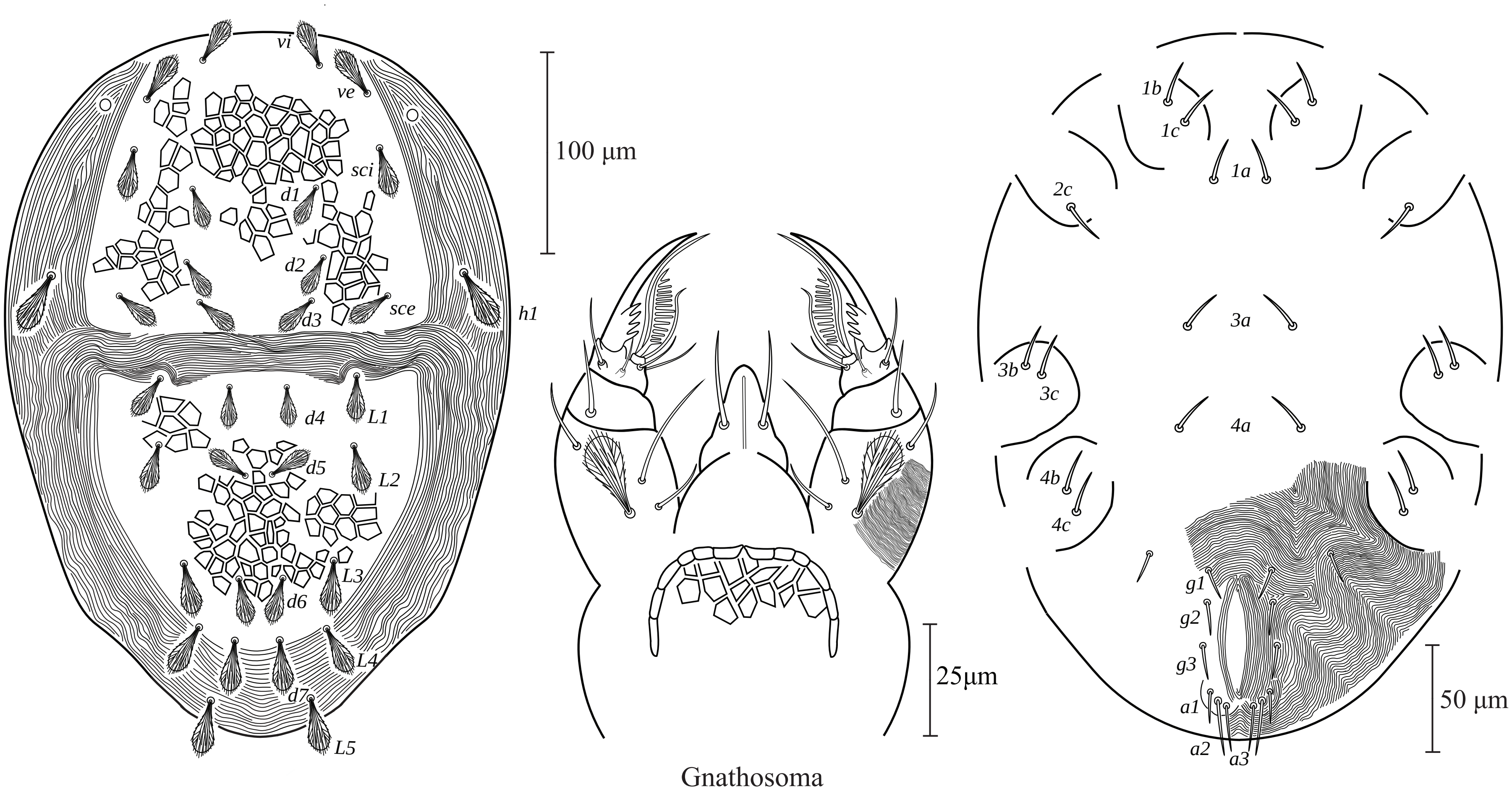
Key to female species of the genus *Acaropsella*

1. Total number of dorsal setae equal or more than 17…..…*A. nobilis* Rasool, Chaudhri & Akbar, 1980
- Total number of dorsal setae less than 17 ……………………………..…..……..… 2
2. Setae *d2* placed off from propodosomal shield ………... *A. schmidtmanni* Price, 1972
- Setae *d2* situated on propodosomal shield ……………...…...………..………...……...3
3. Peritreme with more than 6 links ……………………………….………..……………4
- Peritreme with less than 6 links …………………………..…….……………...…...5
4. Peritreme with 7 links …………………………..……....*A. rohdendorfi* Volgin,1962
- Peritreme with 8 links …………...……..……*A. shaziai* Akbar, Jahan & Mughal, 2008
5. Hysterosomal shield longer than propodosomal shield, palpal teeth equal or more than 5 in number ………………………………..……………………..……….…. 6
- Hysterosomal shield and propodosomal shields almost similar in length, palpal teeth less than 5 in number ……………………………………….……...…………..... 8
6. Propodosomal and hysterosomal shields are separated by membranous area, dorsal setae on genu I-II fan-like ……………….……………..……..…………………… 7
- Propodosomal and hysterosomal shields are not separated by membranous area, dorsal setae on genu I-II hair-like ………..……………….………*A. kulagini* Rohdendorf, 1940

7. Rostral and idiosomal shield with reticulations…........…….*A. kinshasensis* Fain, 1972
- Rostral and idiosomal shield without reticulations…................ *A. volgini* Gerson,1967

8. Comb setae with 13 processes; setae *l1* and *l2* situated on hysterosomal shield; striation present on membranous area around propodosomal and hysterosomal shield; femur IV with one seta.. *A. strioreticulata* Martin & James 2023
- Comb setae with 16 processes; setae *l1* and *l2* placed off hysterosomal shield; striation absent on membranous area around propodosomal and hysterosomal shield; femur IV without setae……...................................……..… *A. walii* Akbar, Jahan & Mughal, 2008

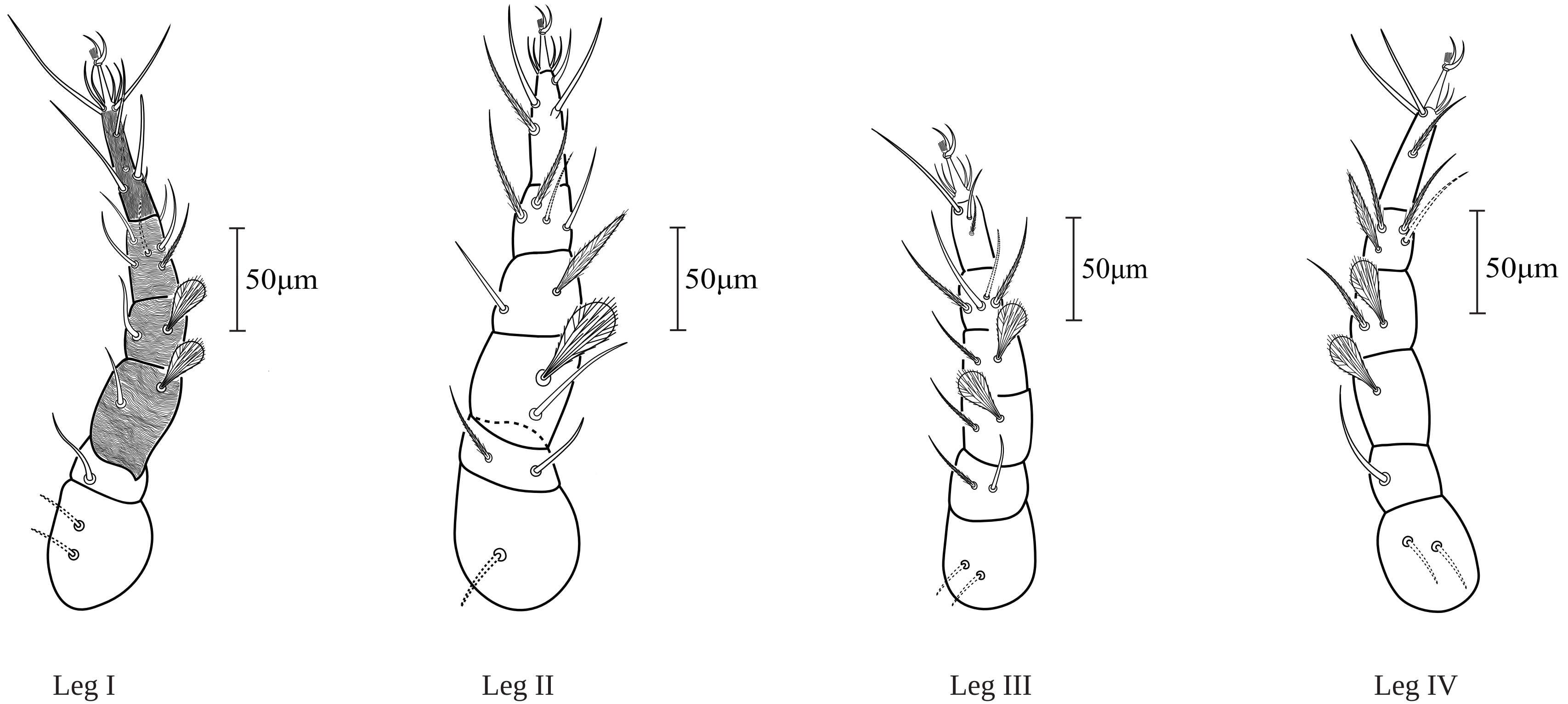
PLATE 16 A



Dorsum Gnathosoma Ventrum

Acaropsella strioreticulata **Martin & James, 2023, Adult female**

PLATE 16 B



***Acaropsella strioreticulata* Martin & James, 2023, Adult female**

Genus *Cheyletus* LATREILLE, 1796

Cheyletus Latreille, 1796: 201; Volgin,1969: 432; 1987: 532 Summers and Price,1970: 26; Summers et al.,1972: 232; Fain and Nadchatram, 1980: 193; Gerson et al., 1999: 55; Fain and Bochkov, 2001a:85; Salarzehi et al., 2018: 465.

***Diagnosis*:** Palpal tarsi comprising four setae, a short ventral solenidion, two dorsal comb-like setae and two sickle-shaped ventral setae. Female palp claw features 1-6 basal teeth; males exhibit 1-3 basal teeth. Palp tibia equipped with 3 slender, hair-like setae. Palpal genu bears 2 setae; femur with 3 setae. Rostral shield ornamented in males. Shape of peritremes variable, typically M-shaped, comprising 5-15 segment pairs with a straightly oriented posterior link. Idiosoma rhomboid or ovoid in shape; Idiosomal length of females nearly twice (2x) the gnathosomal length; males exhibit a moderately shorter idiosoma compared to females (1.7x). Well demarcated propodosomal and hysterosomal plates present, features slender to spatulate, barbed lateral setae. Humeral setae (*c3*) inconsistently elongated; median setae, when present, usually diminutive or unequal. Position of *d2* variable, occurring either on the propodosomal or hysterosomal plate. Ventral setae *a3* consistently barbed; seta *a1* nude or barbed. A pseudosternal shield present in some male species. All legs well formed. Legs II and III narrowly positioned apart, with an interspace of less than one body width. Length of all legs comparable to or shorter than idiosoma. Each tarsus terminates with claws and empodium. Solenidia present on tarsi I-II, tibia and genu I. Guard seta associated with solenidion *ω1* variable in length and features a hair-like morphology. External seta of third coxal segment exhibits serrated margines. Leg chaetotaxy: tarsi 9+*ω*-7-7-7, tibia 5+*φ*-4-4-4, genu 2+*σ*-2-2-2, femur 2-2-2-1/2, trochanter 1-1-2-1, coxae 2-1-2-2. Femur IV of males consistently bears a single seta.

Type species: *Acarus eruditus* SCHRANK, 1781.

Key to the species belonging to genus *Cheyletus* obtained from the present study

1. Peritreme Π-shaped…………………….................….*Cheyletus carnifex* Zachvatkin, 1935
- Peritreme M-shaped……………………..……………………..……………….…...2
2. Femur IV with two setae……………………………..…...…*C. eruditus* (Schrank, 1781)
- Femur IV with one setae………………...……..…….………………………….….3

3. Tarsus I guard seta shorter than solenidion ω; propodosomal shield subequal in length to hysterosomal shield…………….………………...…. *C. trouessarti* Oudemans, 1903
- Tarsus I guard seta two times longer than solenidion ω; propodosomal shield 1.5 times longer than hysterosomal shield……………..…..……*C. malaccensis* Oudemans,1903

Cheyletus carnifex Zachvatkin, 1935

PLATE 17

Cheyletus carnifex Zachvatkin, 1935: 27, Fain and Bochkov, 2001: 90.

Cheyletus aversor Rohdendorf, 1940: 86

Cheyletus beauchampi Baker, 1949: 282

Cheyletus acarophagus Zaher and Soliman, 1967: 25

Cheyletus allactaga Fain and Lukoschus, 1981: 122

Cheyletus zaheri Hassan and Rakha, 1982: 89

Diagnosis

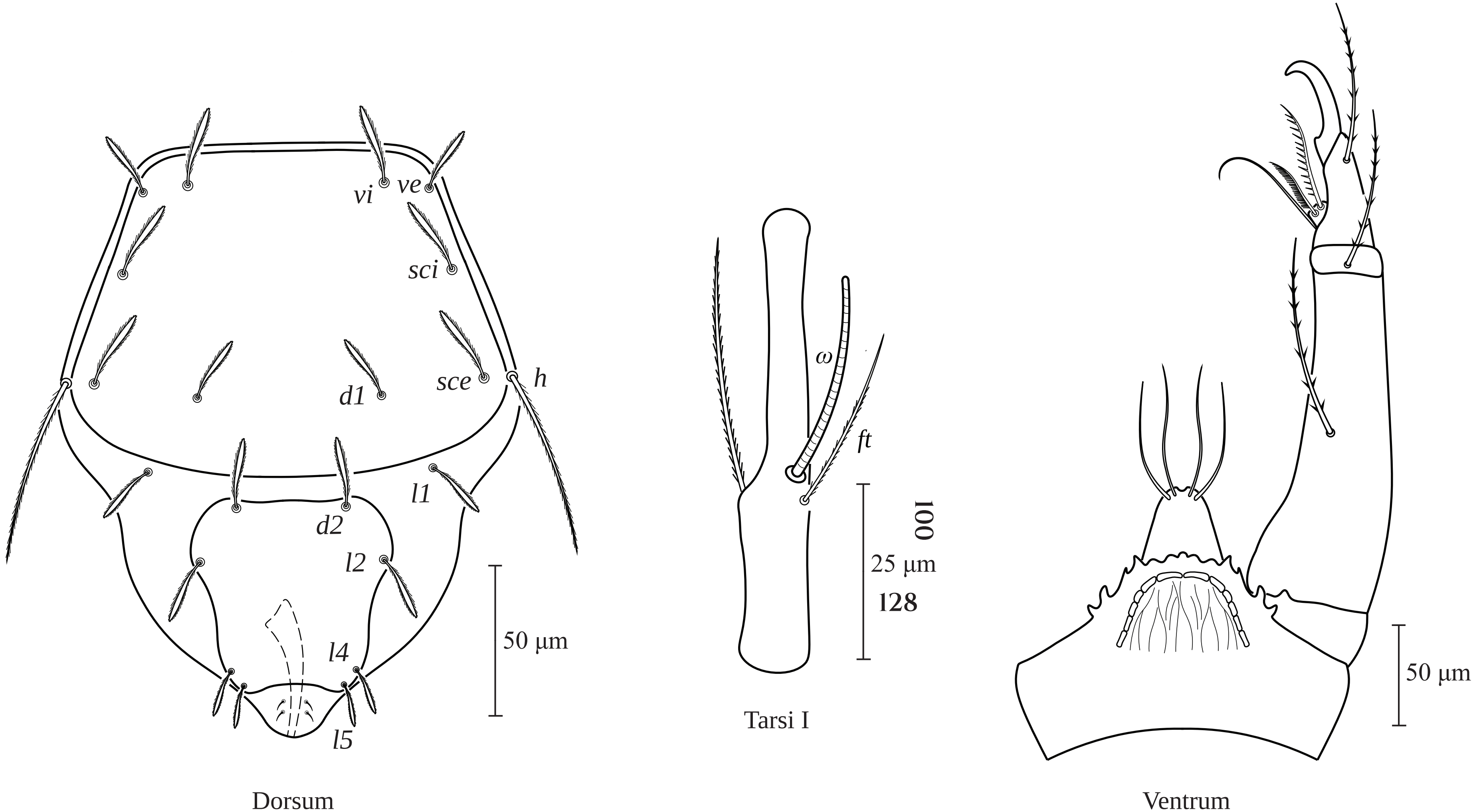
Male: Mean size of idiosoma: 378 x 282 µm. Pedipalp claw features one or two basal teeth, accompanied by an inner comb on the palp tarsus comprising approximately 30 teeth. Prodorsal plate bears five dorsal setae, exhibiting flattened and narrowly spatulate morphology with distinctly barbed margins. Palpal femur elongate, surpassing its width. The hysterosomal shield appears prominently developed, featuring a single pair of dorso-median setae (*d2*) and three pairs of lateral setae. Lateral limb of each peritreme typically comprises six links, forming an inverted U-shaped structure, with the middle region exhibiting a slight obtuse angle in its posterior flexure rather than an acute angle. Guard seta on tarsus I approximates the length of solenidion omega (ω). Femur IV bears a single seta.

Female: Not obtained

Material examined

- Two male specimens from Kozhikode (Chethukadavu 11° 18' 46.5'' N, 75° 54' 8.9'' E), collected from chick pea on 14 October 2019 by Neeraj Martin.

PLATE 17



Cheyletus carnifex **Zachvatkin, 1935, Adult male (heteromorphic)**

Cheyletus eruditus Schrank, 1781

PLATE 18

Acarus eruditus Schrank, 1781: 513.

Eutarsus cancriformis Hessling, 1852.

Cheyletus strenuus Oudemans, 1904: 161.

Cheyletus ferox Banks, 1906: 134.

Chey/etus rabiosus Rohdendorf, 1940: 86.

Cheyletus butleri Hughes, 1948: 106.

Cheyletus doddi Baker, 1949: 279.

Cheyletus mortelmansi Fain, 1972: 37.

Cheyletus desitus Qayyum and Chaudhri, 1977: 90.

Cheletes eruditus (Schrank) Oudemans, 1906: 84.

Cheyletus eruditus Fain and Bochkov, 2001: 86.

Diagnosis

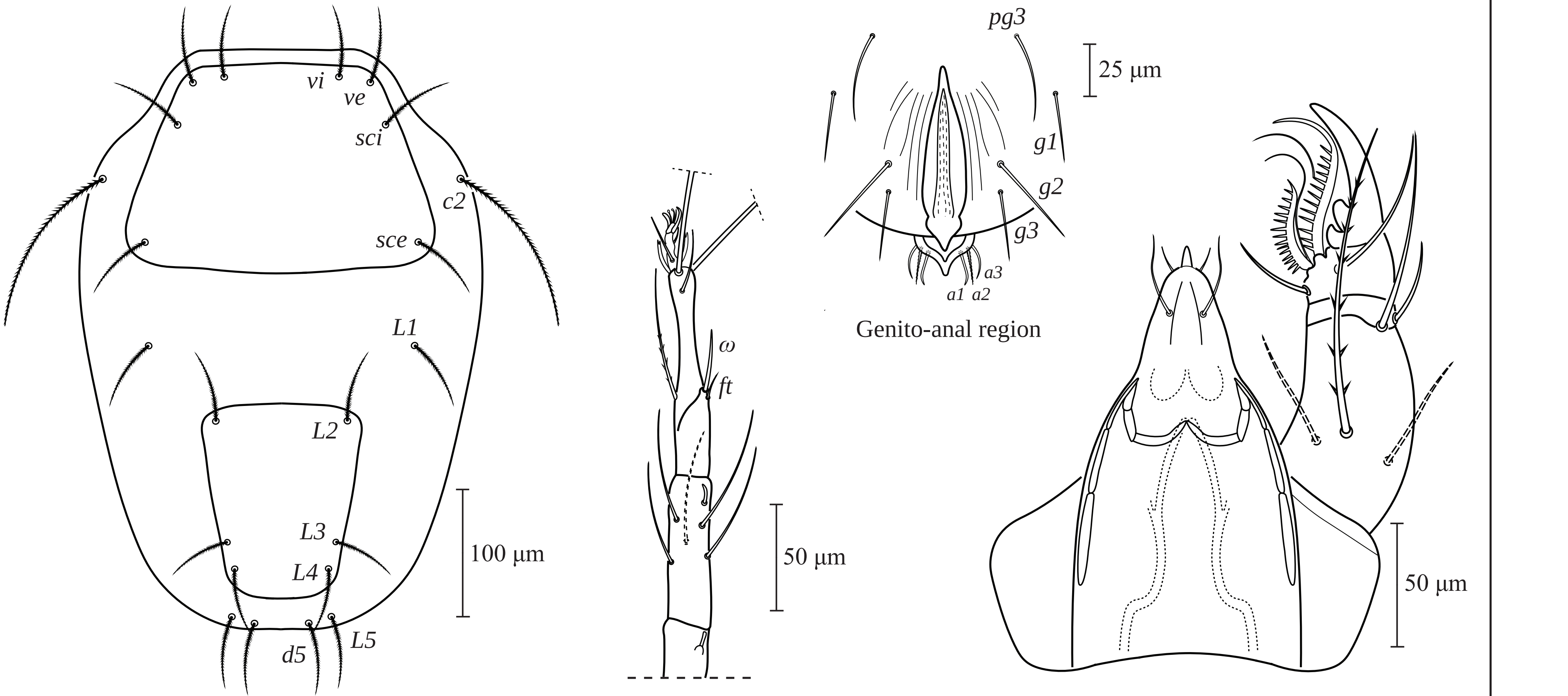
Female: Mean size of idiosoma: 461 x 323 µm. Palpal tarsus features an outer comb-like seta comprising 13 to 15 robust teeth, while the inner comb like seta, displays a distinct curvature, usually possesses 16 or 17 teeth. Palp tibial claw typically exhibits two conspicuously protruding teeth located proximally. A narrowed flange borders the internal edge of the tibia, bearing a tibial seta. External edge of palpal femur exhibits moderate convexity, bears one elongate dorsal seta, sparsely barbed, and prominently projecting. Peritreme reveals a bilaterally symmetrical, M-shaped arrangement, comprising two lateral extensions converging at the median axis, each bearing four to five links. Idiosoma exhibits a diamond-shaped or rhomboidal morphology. Slender and elongated gnathosoma; tegmen marked by radial striae radiating from the basal area. Anterior edge of the propodosomal shield measures shorter than the posterior edge, equipped with four pairs of pectinate and marginally placed dorsal setae. Hysterosomal shield narrowed in outline, distinctly demarcated and isolated from the propodosomal shield, bears three pairs of setae. Sternal shield entirely absent. Tarsus I bears solenidion ω, originating from an elevated and protruding area positioned laterally; not extending towards the tarsal base. A significantly shortened guard seta, positioned proximally posterior to the solenidion ω; solenidia occur on both tibial and genual segments. Solenidion ω on Tarsus II arises ventrally at the midpoint. Femur IV equipped with two setae.

Male: Not obtained.

Material examined:

- Two female specimen from Kozhikode (Central Warehousing Corporation Warehouse- West Hill, 11° 17' 0" N, 75° 45' 43" E), collected from green gram on 24 January 2019 by Neeraj Martin.
- One female specimen from Kozhikode (Supplyco Depot Warehouse- Thamarassery, 11° 23' 26" N, 75° 55' 18" E), collected from stored coriander seeds on 12 February 2019 by Neeraj Martin.
- Two female specimen from Kozhikode (Market Grocery store, 11° 14' 59" N, 75° 46' 36" E), collected from stored foxtail millet and fennel seeds on 27 September 2019 by Neeraj Martin.
- One female specimen from Kozhikode (Atholi, 11° 22' 7" N, 75° 45' 9" E), collected from stored black gram on 10 January 2020 by Neeraj Martin.
- Two female specimen from Kasaragod (Supplyco store- Manjeshwar, 12° 43' 30.08" N, 74° 53' 08.05" E) collected from stored Chickpea on 10 February 2021 by Neeraj Martin.
- One female specimen from Malappuram (Supplyco Depot- Angadippuram, 10° 58' 44.54" N, 76° 12' 27.14" E), collected from stored dried chilly on 07 October 2021 by Neeraj Martin.
- Two female specimen from Palakkad (Supplyco supermarket- Vadakkanthara, 10° 46' 25.88" N, 76° 38' 53.55" E), collected from stored Boiled rice on 27 February 2022 by Neeraj Martin.
- Two female specimen from Kozhikode (Processing Unit- Kunnathara, 11° 24' 56" N, 75° 46' 6" E), collected from stored Copra on 10 November 2022 by Neeraj Martin.

PLATE 18



Dorsum Leg I (Partial) Genito-anal region Gnathosoma

***Cheyletus eruditus* (Schrank, 1781), Adult female**

Cheyletus malaccensis Oudemans, 1903

PLATE 19 A, B

Cheletes malaccensis Oudemans, 1903: 84.

Cheletes vorax Oudemans, 1903: 84.

Cheletes fortis Oudemans, 1904: 161.

Cheyletus munroi Hughes, 1948: 166.

Cheyletus polymorphus Volgin, 1949: 584.

Cheyletus rohdendorfi Zachvatkin, 1949: 290.

Cheyletus caucasicus Zachvatkin, 1949: 288.

Cheyletus ugandanus Lawrence, 1954: 66.

Cheyletus egypticus Elbadry, 1969: 159.

Cheyletus avidus Qayyum and Chaudhri, 1977: 89.

Cheyletus baridos Akbar, Rahi and Chaudhri, 1988: 6.

Cheyletus phantosis Akbar and Aheer, 1994: 342.

Cheyletus wahndoensis Akbar and Aheer, 1994: 343.

Cheyletus malaccensis, Gerson, 1967: 361; Volgin, 1969: 83; Summers and Price, 1970: 25; Hughes, 1976: 242; Regev, 1974: 87; Corpuz-Raros, 1972: 252; Corpuz-Raros and Sotto, 1977: 169; Kumar and Naqvi, 1990: 22; Gupta, 1995: 41; Gupta and Chatterjee, 1997: 517; Fain and Bochkov, 2001: 86; Phaisach et al., 2023: 1591;

Diagnosis

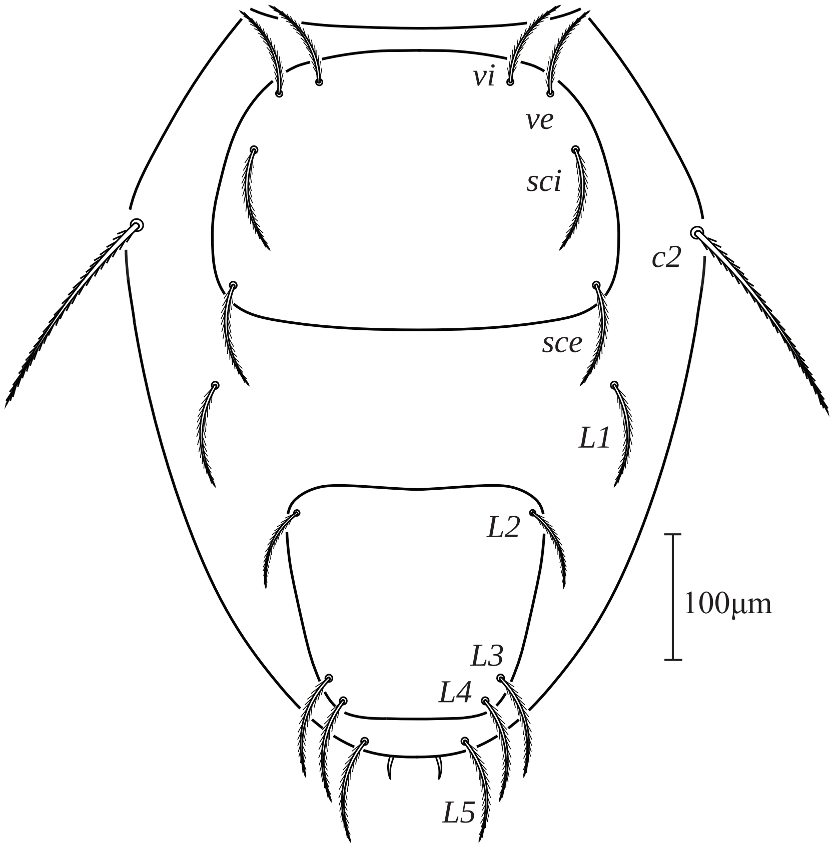
Female: Mean size of idiosoma: 575 x 460 µm. Dorsal surface of the tegmen marked with delicate, faint striations that diminish anterior to the peritreme. Peritreme shaped like letter M, with its lateral arms sharply angled and closely appressed to the lateral walls of the gnathosoma, converging medially. Region spanning from the midline to the lateral arm of the peritreme comprises four or five distinct internal partitions. Pedipalpal tarsus with a relatively straight internal comb like seta featuring 24 to 30 small, delicate teeth; the external comb like seta comprises 18 teeth. Tibial claw bears a two-lobed protrusion proximally with variable morphology. A distinct, slender flange extends proximally from the tibia and reaches the tarsus distally. Anterior edge of the propodosomal shield reduced in length compared to the posterior edge; shield equipped with four pairs of marginal setae, flattened and pectinate, distributed peripherally. Hysterosomal shield, narrower and clearly detached from the propodosomal shield, features three pairs of setae. Setae *pg3* aligned with the anterior edge of the genital opening at the posterior ventral region. Tarsus I with a prominent, expanded solenidion *ω*, accompanied by a short supporting seta tightly appressed against the solenidion.

Male: Mean size of idiosoma: 347 x 284 µm. Dorsal surface of tegmen adorned with delicate striations. Numerous small tubercular protrusions distributed across the dorsal surface of protegmen. Males exhibit polymorphism, consisting of heteromorphic and homomorphic forms. Heteromorphic males are distinguished by an elongated palp femur, in contrast to the reduced palp femur of homomorphic males. Rostrum features alae or lateral extensions that flare or protrude laterally. The region of the rostrum that overlaps the pedipalpal trochanter contains two large denticular projections of unequal lengths. An arciform peritreme present with four to five internal segments or partitions present within the area extending from the converging midline to the initial point of origin of lateral arm. The elongated palp femur of heteromorphs features a prominent inflation or expansion proximally on its internal surface. Palp tarsus bears a pair of comb-like / mono-pectinate setae, with the inner comb displaying 8-11 teeth and the outer comb exhibiting 13-15 teeth, both setae straightly aligned. Tibial claws with a solitary proximal protrusion; males devoid of distinctive flange which occurs in females. Males possess a comparatively smaller idiosoma than females. Propodosomal shield extends over a significant portion of the anterior idiosoma, carrying four pairs of lateral and two pairs of medial setae, all lanceolate and pectinate. Hysterosomal shield gently attenuating towards posterior end and equipped four pairs of setae. A truncated sternal plate stretches posteriorly to the vicinity of coxae II, bounding the first pair of setae on the venter. Tarsus I bears an expanded solenidion, analogous to that seen in females, with shortened, inconspicuous supporting seta.

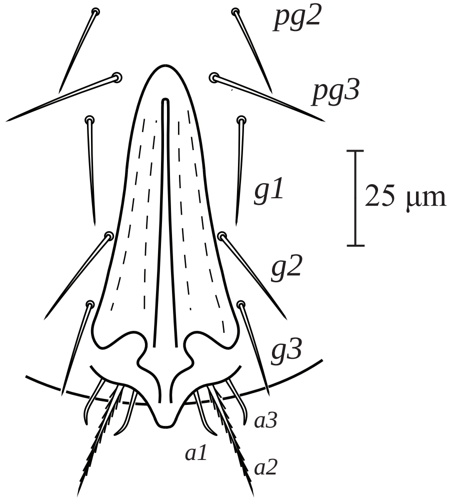
Material examined

A total of 268 specimens were collected from 52 out of 61 surveyed collection sites and slide-mounted for detailed examination, consisting of 220 females, 32 homomorphic males, and 16 heteromorphic males. An additional 500+ specimens are preserved in 90% ethanol for future reference. Collection site information, including geographical coordinates and associated stored products, is summarized in Table 1.

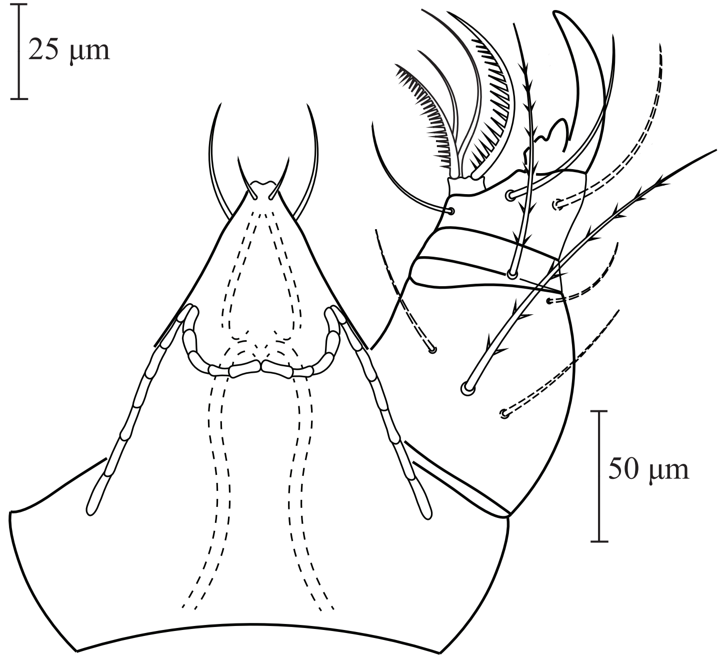
PLATE 19 A



Dorsum



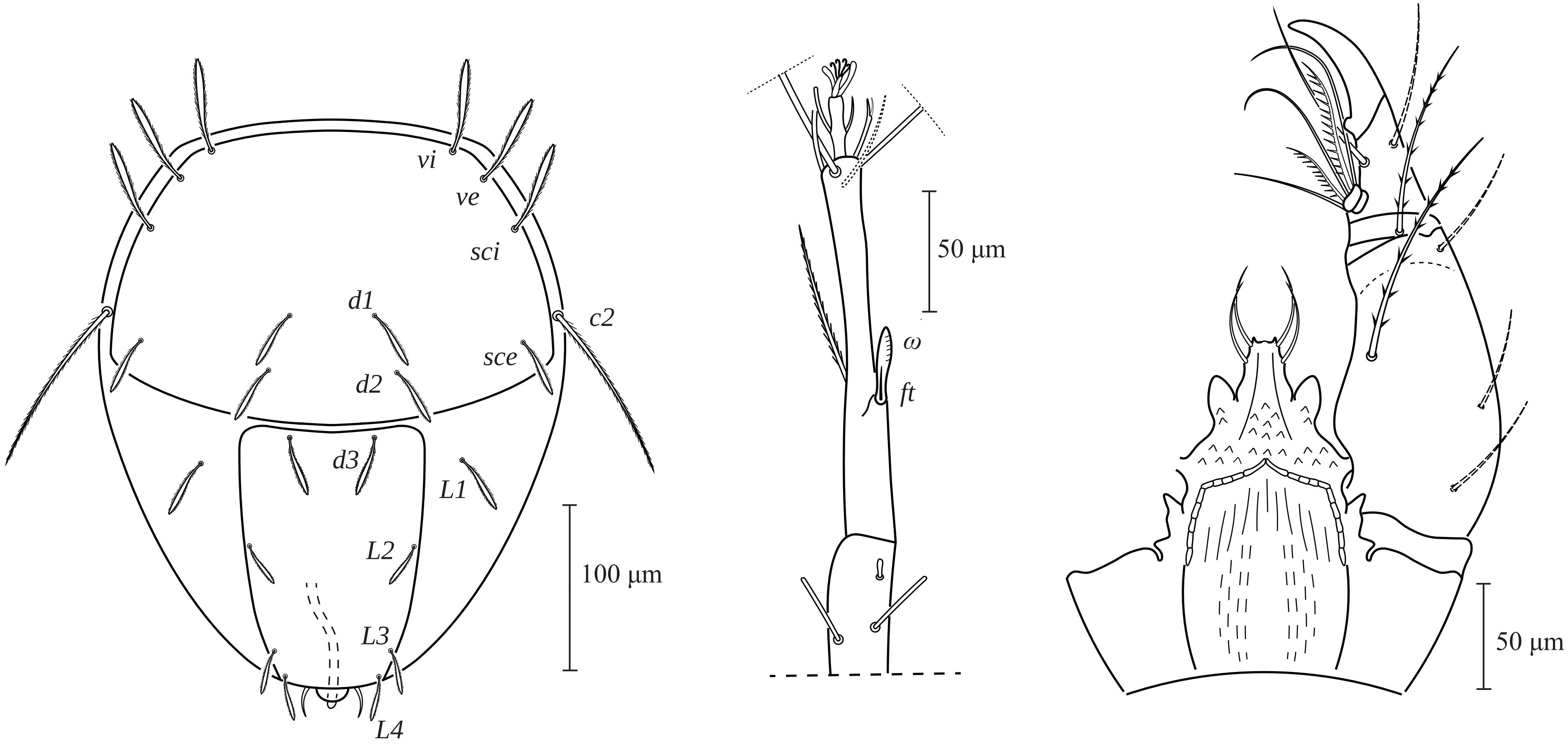
Genito-anal region



Gnathosoma

Cheyletus malaccensis **Oudemans, 1903, Adult female**

PLATE 19 B



Dorsum　Leg I (Partial)　Gnathosoma

Cheyletus malaccensis **Oudemans, 1903, Adult male**

Cheyletus trouessarti Oudemans, 1903

PLATE 20

Cheyletus trouessarti Oudemans, 1903a: 16.

Cheyletus fiwibundus Rohdendorf, 1940: 85.

Cheyletus davisi Baker, 1949: 283.

Cheyletus truculentus Volgin, 1949: 586.

Cheyletus woodroffei Jeffrey, 1979: 47.

Diagnosis

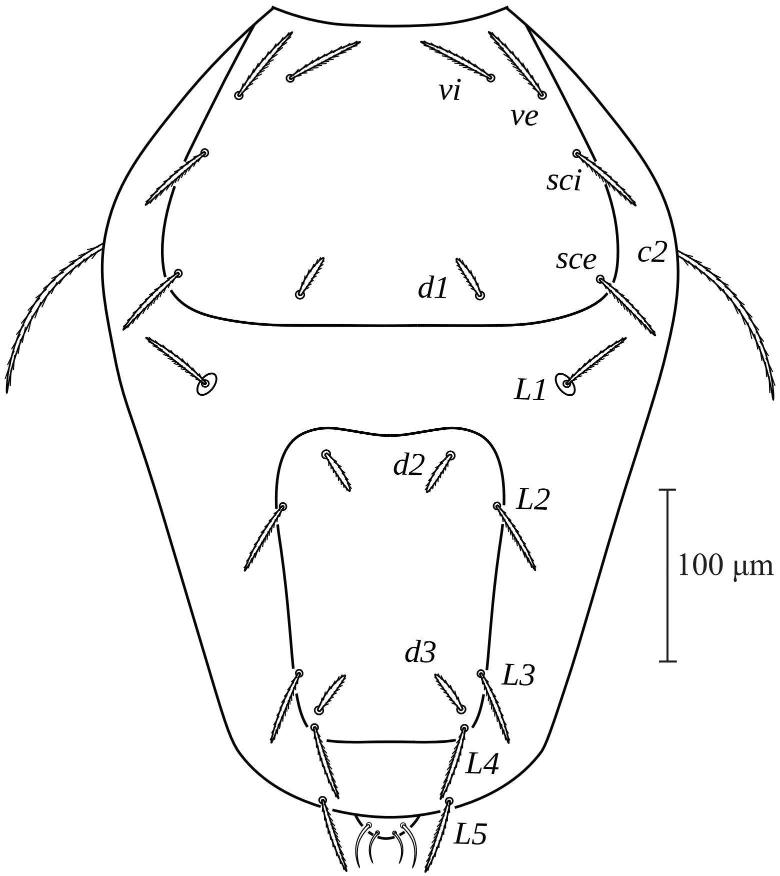
Female: Mean size of idiosoma: 450 x 334 µm. Dorsal anterior surface of the tegmen bears fine stripes; the protegmen lacks striations and tubercular protrusions. The lateral limb of the peritreme forms a sharp angle from its point of origin, extending towards the midline of the converging area, partitioned into four or five internal segments. Internal comb-like seta on the palp tarsus almost aligned straight, comprises around 20 teeth; external comb like seta equipped with approximately 14 teeth. Palp tibial claw typically possesses two to four proximal tooth like protrusions, usually three, but varying with asymmetrical differences within individuals, contingent on dorsal or ventral perspective Anterior edge of the propodosomal shield measures shorter than the posterior edge, equipped with four pairs of flattened pectinate and marginally placed dorsal setae and one medial setae. Hysterosomal shield narrowed in outline, distinctly demarcated and isolated from the propodosomal shield, bears three pairs of setae. Dorso-median setae relatively inconspicuous, comprising one pair on the propodosomal plate and two pairs on the hysterosomal plate. Setae *pg3* positioned postero-laterally, flanking the anterior margin of uropore. Tarsus I bears solenidion ω, originating internally to the slender and elongated supporting seta. Supporting seta approximately double the length of the solenidion.

Male: Not obtained.

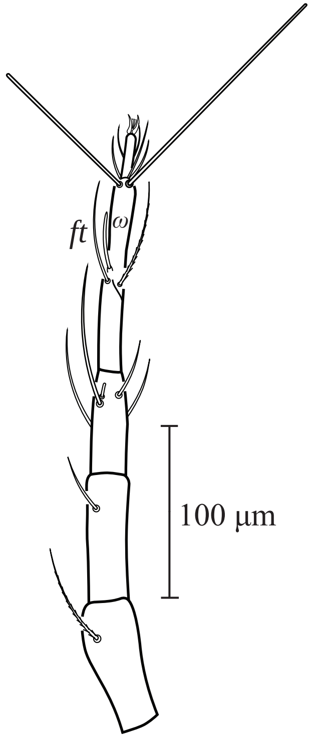
Material examined

- Two female specimen from Wayanad (Food Corporation of India Warehouse-Meeanangadi, 11°39'18.6"N 76°09'22.2"E), collected from wheat on 06 January 2021 by Neeraj Martin.
- Two female specimen from Kasaragod (State warehousing corporation, 12° 30' 11" N, 74° 59' 20" E), collected from stored basmati rice on 09 February 2021 by Neeraj Martin.
- One female specimen from Kannur (Grocery store- Payyannur, 12° 6' 21.75" N, 75° 12' 23.84" E), collected from stored cumin seeds on 11 January 2019 by Neeraj Martin.
- Two female specimen from Kannur (Supplyco Depot Warehouse- Thalipparamba, 12° 02' 28.34" N, 75° 21' 21.52" E), collected from stored finger millet on 28 September 2021 by Neeraj Martin.
- Two female specimen from Malappuram (Supplyco Supermarket- Thanur, 10° 58' 34.21" N, 75° 52' 43.29" E), collected from stored chick pea on 10 June 2022 by Neeraj Martin.
- Two female specimen from Palakkad (Market Grocery store- Valiyangadi, 10° 46' 25.27" N, 76° 38' 46.83" E), collected from stored broken rice on 23 September 2022 by Neeraj Martin.
- One female specimen from Kozhikode (Oil mill- Velur, 11° 24' 15" N, 75° 45' 48" E), collected from stored copra on 10 November 2022 by Neeraj Martin.

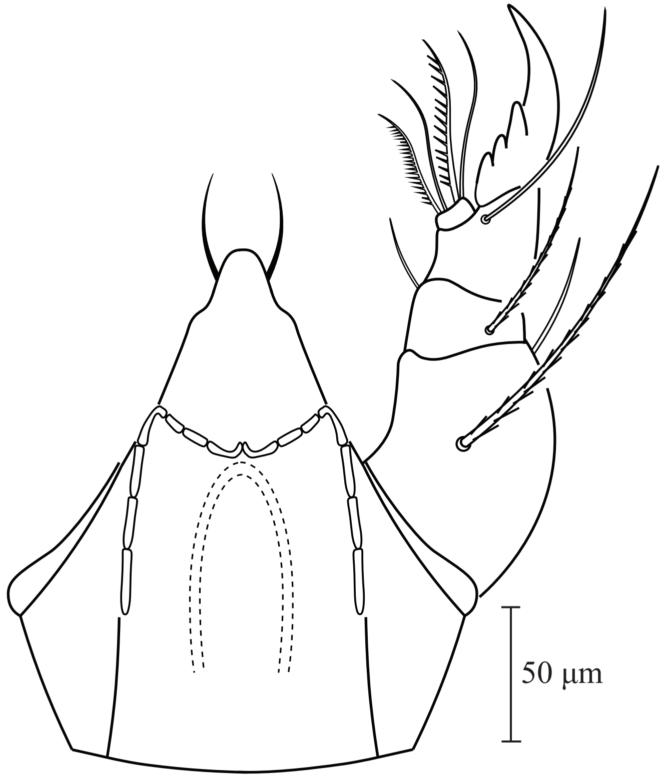
PLATE 20



Dorsum



Leg I



Gnathosoma

Cheyletus trouessarti **Odemans, 1903, Adult female**

4.2.3.7. Family Bdellidae Dugès, 1834

Bdellei Dugès, 1834: 21.

Bdelles Grandjean, 1938: 2.

Bdellidae Thor 1931a: 86, 87; Womersley, 1933: 98; Baker and Balock, 1944: 177; Atyeo, 1960, 347; 1964: 167; Atyeo and Tuxen, 1962: 281; Alberti, 1974: 114, 1975: 46; Alberti and Storch, 1976: 178; Wallace and Mahon, 1976: 66; Kuznetsov and Livshits, 1979: 52; Swift and Goff, 1987: 31; Ostovan and Kamali, 1995: 31; Lin et al., 2006: 3; Bednarskaya, 2009: 21; Maslov and Khaustov, 2013: 52; Hernandes et al., 2016: 2.

Diagnosis: Idiosoma elongated pyriform shaped, featuring an acutely tapered rostrum. Cone-shaped gnathosoma comprises pedipalp and chelicera. Chelicera elongated, bearing one or two dorsal setae, and possess weak digits. Pedipalp five segmented, comprising a shortened genu, tibia, and a variably lengthened femur, featuring a leg-like appearance. Genu and tibia bent, yielding pedipalp a distinctive elbow-like appearance. Palptarsus apically bears one dorsal end seta and one ventral end seta; both markedly elongated. Hypostomal setation variable. Idiosoma distinctly demarcated into propodosoma and hysterosoma; a differentiating suture found between two regions. Dorsal integument exhibits uninterrupted to fragmented, straight to slightly undulate, parallel striae. Propodosoma provided with one pair of anterior trichobothria and one pair of posterior trichobothria. Hysterosoma equipped with 8 pairs of setae, comprising *c1*-*c2*, *d1*, *e1*, *f1*-*f2*, *h1* and *h2*. Prodorsum exhibits one or two pairs of eyes, with the posterior pair occasionally devoid of lenses. An unpaired median eye rarely present. Leg I-IV features trichobothria, solenidia on tarsi, tibiae and genua. Trichobothria distributed on tibiae I, II (variably), IV and tarsi III-IV. Solenidiotaxy on tarsi as follows: tarsus I with two attenuate and two elongated, blunt solenidion, accompanied with a diminutive peg like solenidion; tarsus II bears one attenuate and two blunt solenidion including a peg like solenidion; tarsi III and IV equipped with a proximally placed trichobothria.

Type genus: *Bdella* Linnaeus, 1758.

Genus *Bdella* Latreille, 1795

Bdella Latreille, 1795: 18; 1810: 133; Berlese, 1893: 42; Oudemans, 1929: 303; Meyer and Ryke, 1959: 373; Atyeo, 1960: 372, 1963: 120, 170; Soliman and Zaher, 1975: 79; Chaudhri et al., 1979: 130; Gupta, 1991: 220; van Der Schyff et al., 2005: 222; Hernandes et al., 2008: 262; 2016: 44.

Chelifer Geoffroy, 1762: 617.

Scirus Hermann, 1804: 60.

Bdellidium Oudemans, 1929: 449.

Caenobdella Oudemans, 1937: 1227.

Diagnosis: Chelicerae normal to enlarged in form, featuring two setae, each positioned on the proximal and distal halves, small chelae possess arcuate movable digits, bearing a single, diminutive tooth. Palp tibiotarsus segment shortened; markedly shorter in comparison to palp basifemur; subequal terminal setae either comparable in length or exceeds palp femoral length. Palp basifemur equipped with 8-13 setae. Dorsal idiosoma features two longitudinal, moderately demarcated dorsal plates. Propodosomal shield ornamented with longitudinal or transverse striations; delicately fragmented or uninterrupted. Dorsal propodosoma bear four pairs of eyes positioned laterad posterior pseudostigmatic organs. A single pair of anterior and posterior trichobothria present. Prodorsal striae between posterior trichobothria either arched posteriorly or aligned longitudinally. Dorsal hysterosomal setae vary in morphology, being serrate, distally branched, distally pointed, nude, or plumose. Podocephalic canal represented by an external groove. Legs devoid of thickening. Trichobothria on tarsus IV and duplex setae on genu I-IV inconsistently present. Tibia II bears one or two solenidia.

Type species: *Bdella longicornis* (Linnaeus, 1758)

Bdella distincta Baker and Balock, 1944

PLATE 21

Bdella distincta Baker and Balock, 1944: 179; Atyeo, 1960: 381; Chilson, 1963: 206; Garrett and Haramoto, 1967: 396; Tseng, 1978: 36; Swift and Goff, 1987:44; Howard et al., 1990: 249; Medina et al., 1991: 305; Hernandes et al., 2016: 12.

Diagnosis

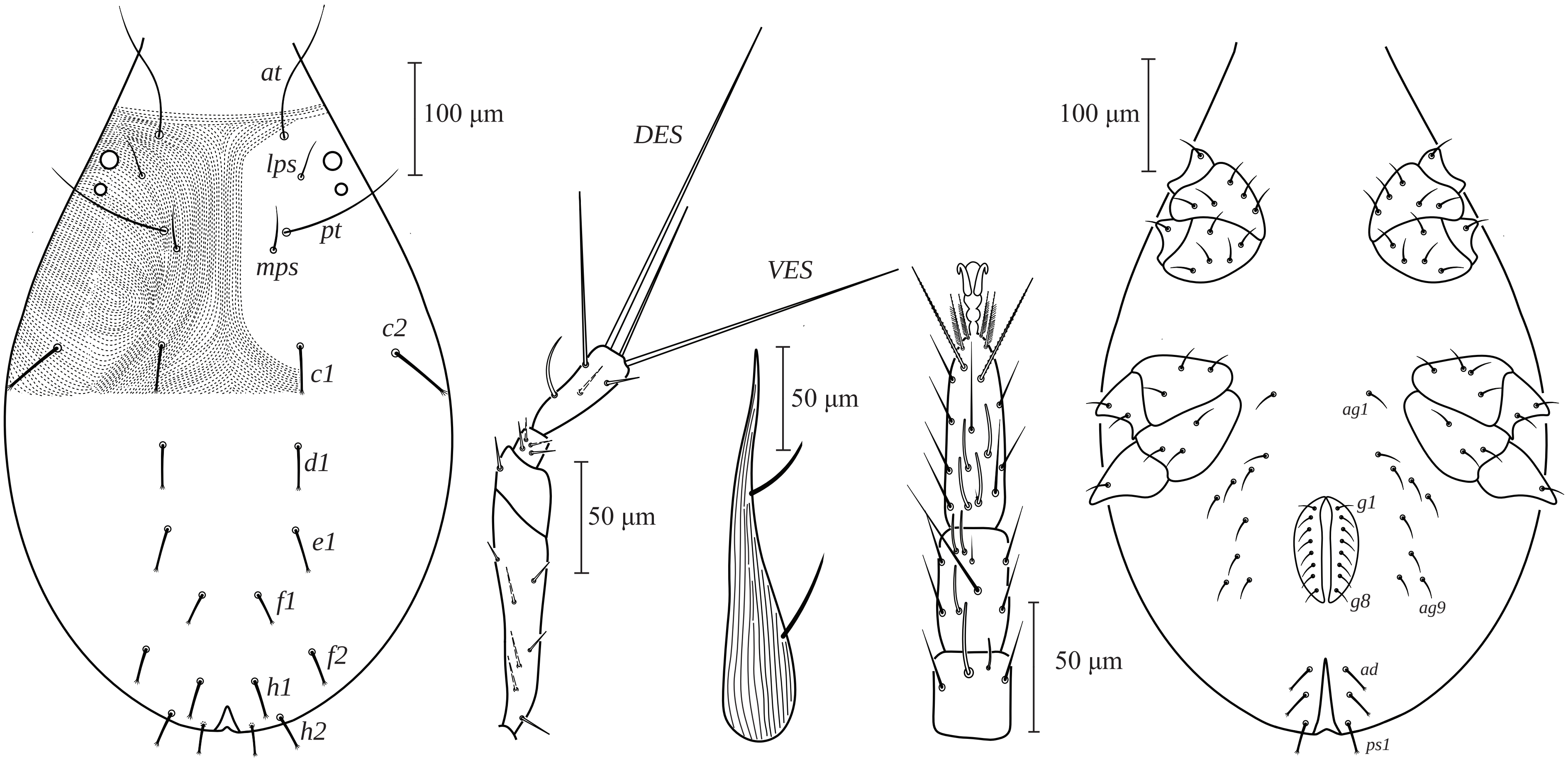
Female: Mean size of idiosoma: 575x365 µm. Idiosoma oval in shape and constricted. Pedipalp shortened, with distal 2/3rd of tibiotarsus surpassing hypostome. Palpal telofemur bears only one seta. In addition to the normal setation, palp tarsus equipped with a ventral end seta and one dorsal end seta, both conspicuously elongated. Chelicera appears normal, comprising equally lengthened fixed and movable digits, bearing fine striations and a smooth chela, with the fixed digit sharply tapering. Distal seta not extending beyond the tip of chela, proximal seta reaches midway to the distal seta. Hypostome devoid of striae. Prodorsal striae sparsely broken, oriented longitudinally, running between anterior trichobothria and posterior trichobothria. Two pairs of eyes, each consisting of a larger and slightly smaller one, positioned lateral to posterior trichobothrium, with transverse striae separating each pair. Lateral proterosomal setae and medial proterosomal setae simple and setiform. Dorsal setae (*c1*, *c2*, *d1*, *e1*, *f1*, *f2*, *h1* and *h2*) thickened, sparsely branched apically. Dorsal hysterosoma exhibits delicately broken striae. One pair of anal seta (*ad*) inserted near anterior end of the cleft. Terminally branched paranals originate posterior to laterally aligned striae, and apically branched postanals (*ps1*) located near the cleft's termination point, less elongated than setae *h2*. Individual genital plate features a linear array of eight diminutive genital setae (*g1-8*), along with 9 pairs of paragenital setae (*ag1-9*), the anterior pair (*ag1*) positioned between coxae IV. Coxae I-IV lacks striations. Tarsus IV equipped with 8 ventral plumose setae, 4 lateral setae, a trichobothrium and a single attenuate sensory seta (*asl*) distally positioned to the dorsoterminals and the trichobothrium.

Male: Not obtained.

Material Examined:

- One female specimen from Kasargod (State Warehousing Corporation, 12° 30' 11'' N, 74° 59' 20'' E), collected from stored pepper on 09 February 2021 by Neeraj Martin.
- One female specimen from Kasargod (Kadumeni, 12°17'25.4"N, 75°20'41.9"E), collected from stored pepper on 12 March 2021 by Neeraj Martin.

PLATE 21



Dorsum Palp Chelicera Leg I (partial) Ventrum

Bdella distincta Baker **and Balock, 1944, Adult female**

Genus *Spinibdella* Thor, 1930

Spinibdella Thor, 1930a: 22; 1931a: 39; 1931b: 70; Willmann, 1939a: 39; 1939b: 532; 1952: 165; Baker and Wharton, 1952: 179; Atyeo, 1960: 424; 1963: 121, 172; Wallace and Mahon, 1972: 563; Soliman and Zaher, 1975: 80; Omukunda et al., 2012: 3; Paktinat-Saeej et al., 2015: 693.

***Diagnosis*:** Chelicerae elongated and finely striated; each bearing two subequal setae positioned mid-proximally and mid-distally along its length; distal seta not surpassing beyond small, slender chelae. Palp tibiotarsus short, truncated, and apically inflated. Palp tarsus features five to seven setae, comprising a long dorsal end seta (*DES*) and a ventral end seta (*VES*). Palp trochanter asetose. Palp tibia usually comprises three to four setae. Propodosoma and hysterosoma ornamented with uninterrupted longitudinal striations, or delicately fragmented transverse striations. Slender anterior and posterior trichobothria present. Position of lateral proterosomal setae varies, occurring closer proximity to either the posterior or anterior trichobothria. Two pairs of eyes present. Dorsal setal morphology inconsistent, ranging from smooth to minutely barbed, lanceolate, finely plumose, or delicately branched. Females possess 8-18 genital setae. Tarsus of leg I equipped with 1-3 sharply attenuate solenidia (*asl*). Coxa I features a minimum of one simple tactile seta. Striation pattern on prodorsum and modified setae on amphioid sclerites of males, inconsistent among species.

Type species: *Spinibdella reducta* Thor, 1930

Spinibdella ampulla Wallace & Mahon, 1972

PLATE 22

Spinibdella ampulla Wallace and Mahon, 1972: 568.

Diagnosis

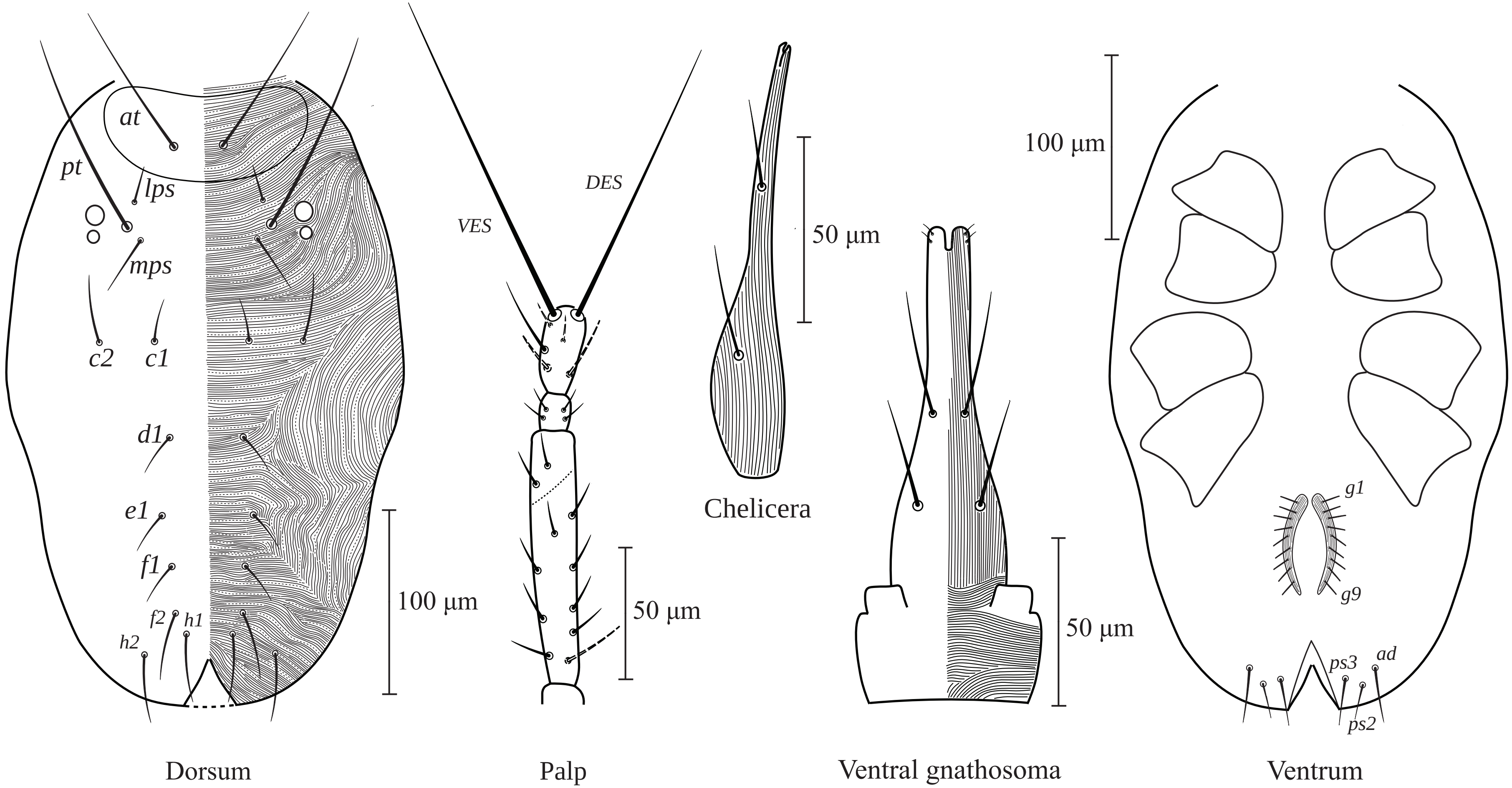
Female: Size of idiosoma (including gnathosoma): 347 x216 µm. Pedipalp reaches to distal extremity of hypostome. Chelicerae slender, inflated proximally and adorned with delicate vertical striations, bearing normal setae. Fixed cheliceral digit straight, movable digit arcuate, comparable in length with fixed digit. Gnathosomal base features transverse striations, extending up to proximal palp basifemur; striations on median proximal area prominently recurved posteriorly. Ventral hypostome exhibits delicate vertical striations. Palp basifemur provided with nine setae, palp telofemur bears two setae, and palp genu equipped with four setae. Palp tibiotarsus complex comprises solenidion ω, one dorsal end seta and one ventral end seta. Lateral proterosomal setae delicate, positioned close proximity to posterior trichobothria compared to anterior trichobothria. Two pairs of eyes observable, positioned in close proximity to each other. Prodorsum ornamented with intermittently fragmented striations; almost continuous and horizontally aligned across mid region; featuring anterior curvature symmetrically. Opisthodorsum covered with intermittently fragmented striations, mostly continuous. Ventral idiosoma adorned with uninterrupted striations. Genital plates possess nine blunt setae inserted in an arcuate alignment. Tibia II equipped with a firmly entrenched blunt solenidion.

Male: Not obtained.

Material examined:

- One female specimen from Kannur (Supplyco PDS depot- Dharmashala, 11° 58' 59" N, 75° 22' 36" E), collected from stored raw rice on 16 July 2021 by Neeraj Martin.

PLATE 22



Spinibdella ampulla **Wallace & Mahon, 1972, Adult female**

Spinibdella tabarii (Paktinat-Saeej & Bagheri, 2015)

PLATE 23

Spinibdella tabarii Paktinat-Saeej et al., 2015: 696

Diagnosis

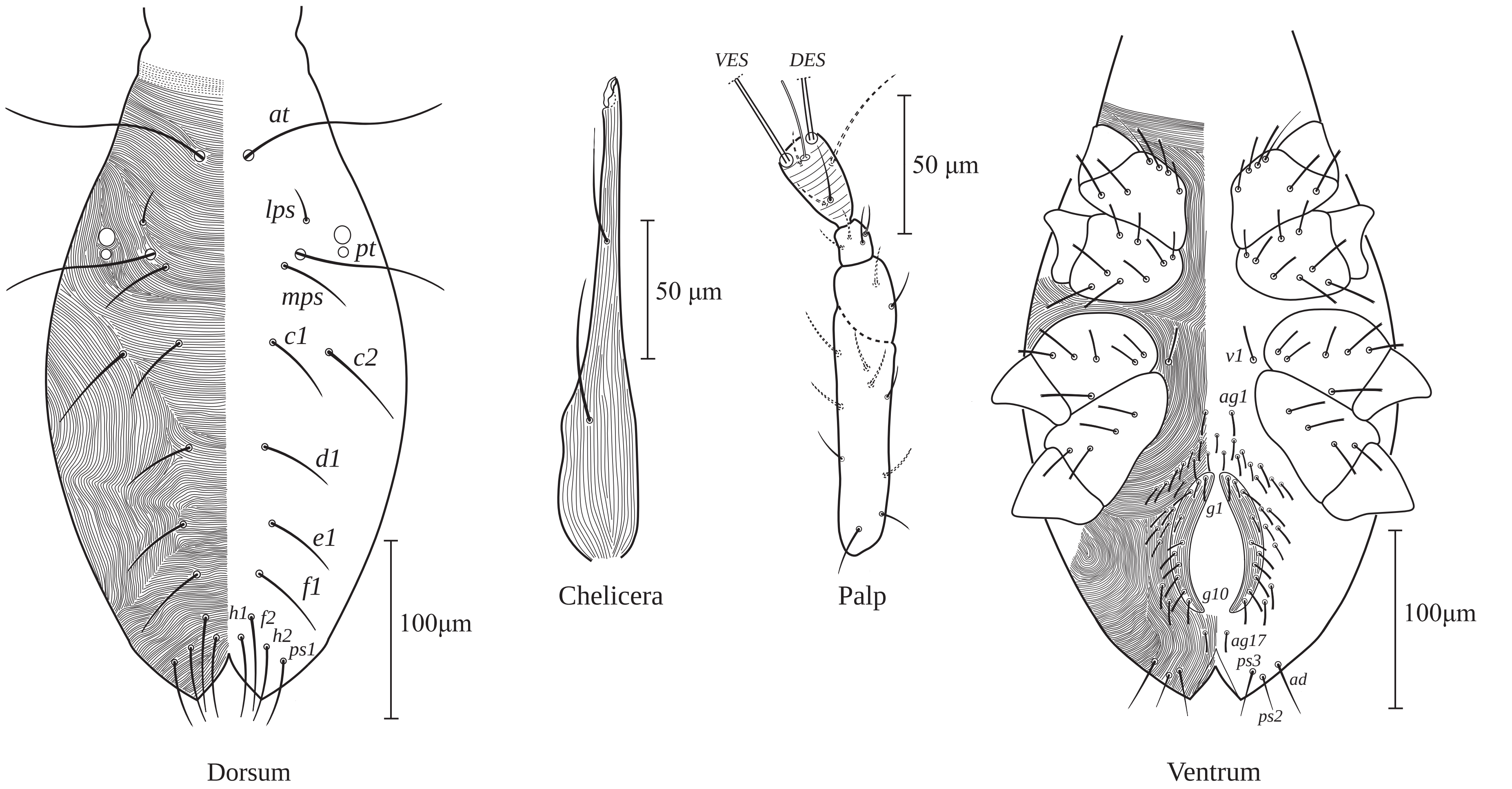
Male: Size of idiosoma: 386 x 202 µm. Chelicera ornamented with longitudinal striations and features two setae; proximal seta 1.5 times longer than distal seta. Movable digit of chelicera slightly elongated than fixed digit, both digits smooth and distinctly reduced. Palp basifemur comprises 9 setae, tibiotarsus bears a single conspicuously long ventral end seta and a dorsal end seta. Hypostome provided with two pairs of vertically positioned ventral hypostomal setae (*vh1–vh2*). Hypostome terminally bifurcates in two lateral flanges, complemented with two adoral setae (*ad1*, *ad2*). Ventral surface of hypostome exhibit scattered longitudinal striae distally and transverse striae proximally. Anterior trichobothria and posterior trichobothria slender and devoid of ciliations or barbs. Median propodosoma displays uninterrupted to Intermittently fragmented transverse striations; lateral margins longitudinally striated. Two pairs of eyes present, anterior pair larger than posterior pair in diameter, aligned anterolaterally relative to the posterior trichobothria; interspacing area between each pair marked with transverse striations. Lateral proterosomal setae (*lps*) positioned in close proximity to the posterior trichobothria (*pt*) than to the anterior trichobothria (*at*). Ventral setae smooth and simple. Genital plate comprises ten genital setae, aligned longitudinally. Ventral opisthosoma features 15–17 aggenital setae. Anal valves provided with three pairs of pseudanal setae (*ps1–ps3*) and one pair of adanal segment setae (*ad*) located lateral to the third pseudanal setae. Intercoxal space of coxae III features one pair of setae *v1*. Tarsus I with two attenuated solenidion, two basal solenidion and one peg like solenidion.

Female: Not obtained.

Material examined:

- One female specimen from Kannur (Central warehousing corporation Warehouse-Dharmashala, 11° 58' 59" N, 75° 22' 36" E), collected from stored raw rice on 12 February 2020 by Neeraj Martin.

PLATE 23



Spinibdella tabarii **(Paktinat-Saeej & Bagheri, 2015), Adult male**

4.2.3.8. Family: Cunaxidae Thor, 1902

Cunaxidae Thor, 1902: 161; Oudemans, 1906a: 242; Thor and Willmann, 1941: 165; Meyer and Ryke, 1959: 376; Muma, 1960: 323; Smiley, 1975: 230; Chaudhri, 1977: 43; Gupta, 1985: 313; 1991: 212; Hu, 1997: 57; Baker and Hoffman, 1948: 234; Sergeyenko, 2005: 160; Kaluz, 2009: 28; Den Heyer, 1980: 3; Skvarla et al., 2014: 8.

Diagnosis**:** Palp comprises three to five segments and terminally features a robust claw. Palp length variable, shortened or surpassing distal subcapitulum. Femora of five-segmented pedipalps typically partitioned into basi and telofemora with a demarcating line. Position of apophyses variable on telofemora; may occur in close proximity to genua and tibiotarsi, or on tibiotarsi. Subcapitulum deltoid in shape, may display punctures, papillae, striations, reticulations, or cell arrays proximally; *hg1* aligned straight and *hg4* markedly elongated. Chelicerae variably bear setae near cheliceral digit. Idiosoma rhombus or diamond shaped. Proterosomal shield features one pair of lateral and one pair of medial proterosomal setae along with one pair of anterior and one pair of posterior trichobothria. Dorsal hysterosoma bears 0-4 large plates; typically complemented with 8 pairs of setae with *h2* positioned ventrally. Dorsal setae may arise from diminutive sclerites slightly larger than setal sockets. Membranous integument devoid of shields or plates. Cupule *im* positioned posterior to *e1*. Dorsal shields and plates may be smooth or adorned with punctures, papillae, reticulations, striations or cell arrays. Ventrum may features one or few small plates excluding coxal plates. Coxae coalesced with body, forming plates. Coxae of legs I–II often confluent medially, constituting a sternal shield; coxae III–IV frequently extend caudally beyond genital plates. Coxae may be smooth or exhibit punctures or papillate textures; may bear up to four setae Adult genital plates usually possess four setae. Anal plate comprises *ps1–2*; *ps2* may be situated off the plate. Trichobothrium present on tibia IV. Ambulacral claws flank a four-rayed empodium.

Type Genus: *Cunaxa* Von Heyden, 1826

Genus *Cunaxa* Von Heyden, 1826

Scirus Hermann, 1804: 62; Voight and Curvier, 1836: 444; Gervais, 1841: 6; Koch, 1842: 76; Kramer, 1877: 234; Berlese, 1887: 34; 1897: 138; Hull 1918: 37.

Cunaxa Von Heyden, 1826: 609; Thor and Willmann, 1941: 165; Baker and Hoffmann, 1948: 230; Baker and Wharton, 1952: 193; Meyer and Ryke, 1959: 370; Hughes, 1959: 225; Muma, 1960: 322; Heryford, 1965: 310; Shiba, 1969: 106; Smiley, 1975: 238; Hughes, 1976: 257; Chaudhri, 1977: 41; den Heyer, 1980: 6; Chaudhri et al., 1979: 182; Kuznetsov and Livshits, 1979: 51; Tseng, 1980: 253; Gupta and Ghosh, 1980: 194; Smiley, 1992: 153; Corpuz-Raros and Garcia, 1995: 605; Khaustov and Kunetzov, 1998: 1332; Sergeyenko, 2003: 225; 2009: 8; Krantz and Walter, 2009: 237; den Heyer and Sergeyenko, 2009: 61; den Heyer et al., 2011: 1668; Skvarla et al., 2014: 53.

***Diagnosis*:** Pedipalp comprised of five segments and protrudes beyond subcapitulum. Palp tibiotarsal complex terminates in a robust claw. Palp telofemora and basifemora features dorsolaterally positioned simple setae; telofemora inconsistently bear a distinct apophysis. Palp genu and tibiotarsal complex may possess a thickened spiniform setae. Subcapitulum contains six setae: *ao1*, *ao2*, *hg1*, *hg2*, *hg3*, and *hg4*. Subcapitulum and dorsal shield smooth or marked with scattered punctations or fragmented striations. Proterosomal shield comprises anterior and posterior trichobothria, lateral and medial proterosomal setae. Dorsal hysterosomal shield with four pairs of setae, sometimes entirely absent. Dorsal setae *c1*, *c2*, *d1*, *e1*, *f1* and *h1* positioned on diminutive platelets; slightly larger than setal sockets. Cupule *im* positioned in posterior proximity to setae *e1*. Genital plates possess four setae. Anal plates with one pair of pseudanals, one pair of *h2* positioned off the plate but placed in close proximity. Coxae I may coalesce with II, similarly, coxae III with IV. Chaetotaxy of coxae II-IV: 1-3-2. Tibia IV exhibits a trichobothrium. Slender, distally tapered and elongated tarsi feature inconspicuous tarsal lobes. Ambulacral claws and empodium present.

Type species: *Scirus setirostris* Hermann, 1804

Cunaxa capreolus (Berlese, 1889)

PLATE 24

Scirus capreolus Berlese, 1889: 63; 1897: 138; Trägårdh 1905: 6.

Cunaxa capreolus Thor and Willmann 1941: 166; Baker and Hoffmann 1948: 231; Kuznetzov and Livshitz,1979: 64; Smiley 1992: 162; Corpuz-Raros and Garcia 1995: 607; den Heyer et al., 2011: 1673; Skvarla et al., 2014: 53

Cunaxa capreola den Heyer 2009: 22.

Diagnosis

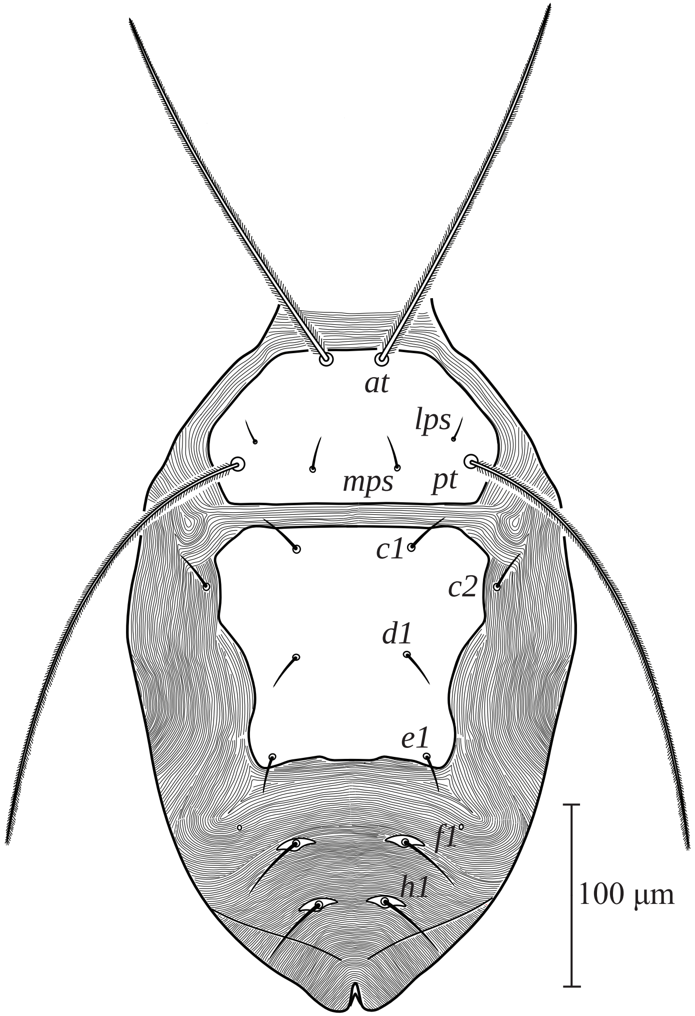
Female: Mean size of idiosoma: 380 x 240 μm. Pedipalp comprises five segments. Palp chaetotaxy as follows: trochanter asetose; basifemur with one dorso medially positioned simple seta; telofemur features a single prominent, robust, uncinated apophysis on the inner anterior surface and a dorsolaterally placed simple seta on the external surface. Palp genu possess a moderately stout spiniform seta on the inner surface and a slender simple seta dorso-laterally; tibiotarsus complemented with one elongated simple seta on the inner surface, one stout spiniform seta medially, and two adjacent simple setae, while the external surface apically bear a single dorsolaterally placed simple seta and a small claw. Propodosomal shield features one pair of anterior trichobothria and one pair of posterior trichobothria, both significantly elongated and extending more than half the length of the idiosoma, along with one pair of lateral proterosomal setae and one pair of medial proterosomal setae. Hysterosomal shield features three pairs of subequal-sized setae, with setae *c2* positioned outside the hysterosomal shield. Propodosomal and hysterosomal shields distinctly demarcated and separated by a narrow, well-defined band of striation. Setae *f1* and *h1* setae originate from diminutive platelets. Genu I exhibits a very short attenuate solenidion proximally. Striation on the anterolateral corners of the propodosomal shield delicate and less prominent, contrasting with the pronounced striation encircles the hysterosomal shield. Each genital plate bears 4 pairs of genital setae (*g1*-*g4*). Leg chaetotaxy: coxae I–IV; 3–1–3–1; trochanters I–IV; 1–1–2–1; basifemora I–IV; 4–4–3–1; telofemora I–IV; 4–4–4–4; genua I-IV; 2 asl, 5 setae- 2 asl, 1 asl, 4 setae - 1 solenidion κ, 5 setae– 1 κ, 5 setae; tibiae I-IV; 1 φ, 6 setae-1 φ, 5 setae- 1 φ, 5 setae, 1 trichobothrium, 4 setae; tarsi I–IV; 21–24–23–20.

Male: Not obtained

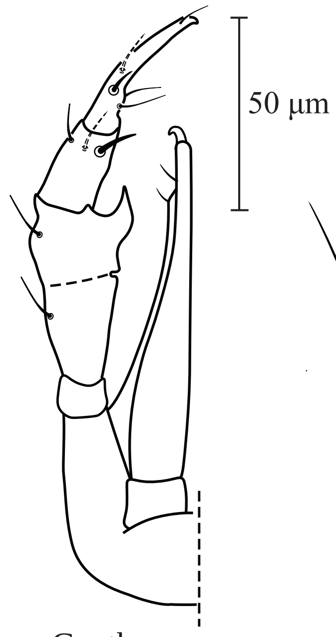
Material examined:

- Two female specimen from Kozhikode (Market Warehouse, 11° 14' 56.4" N, 75° 46' 38.0" E), collected from stored foxtail millet and mustard on 4 December 2018 by Neeraj Martin.
- One female specimen from Wayanad (State Warehousing Corporation Warehouse-Kalpetta 11° 36' 53" N, 76° 4' 25" E), collected from stored pepper on 06 January 2021 by Neeraj Martin.
- One female specimen from Kasargod (Supplyco district depot 12° 30' 10" N, 74° 59' 20" E), collected from stored raw rice on 09 February 2021 by Neeraj Martin.
- One female specimen from Malappuram (Supermarket- Manjeri 11° 06' 35.83" N, 76° 07' 15.03" E), collected from stored pepper on 26 November 2021 by Neeraj Martin.
- One female specimen from Malappuram (State warehousing Corporation- Manjeri) 11° 08' 04.16" N, 76° 06' 51.41" E), collected from stored Wheat on 22 April 2022 by Neeraj Martin.
- One female specimen from Palakkad (Central Warehousing Corporation- Pudussery) 10° 47' 14.69" N, 76° 47' 07.67" E), collected from stored boiled rice on 28 October 2022 by Neeraj Martin.

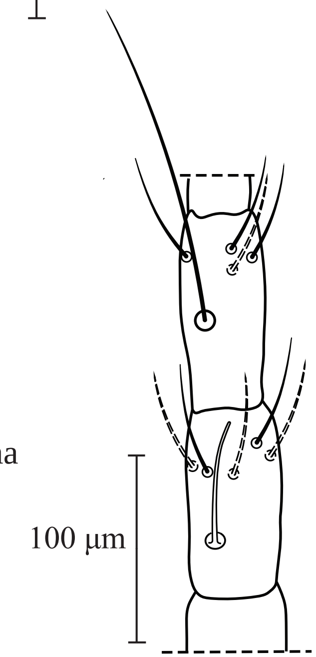
PLATE 24



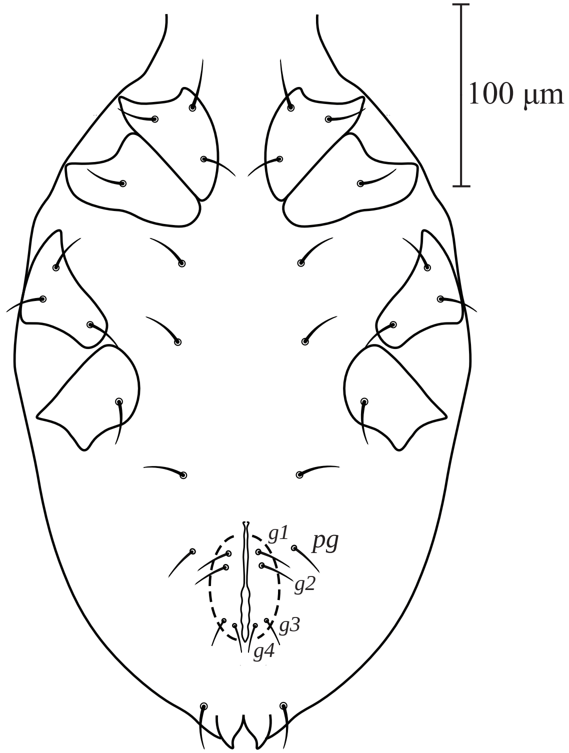
Dorsum



Gnathosoma



Leg IV (genu & tibia)



Ventrum

Cunaxa capreolus **(Berlese, 1889), Adult female**

Cunaxa setirostris (Hermann, 1804)

PLATE 25

Scirus setirostris Hermann, 1804: 62; Voight and Curvier, 1836: 444; Gervais, 1841: 6; Koch, 1842: 76; Kramer, 1877: 234; Berlese, 1887: 34; 1897: 138; Hull, 1918: 37.

Cunaxa setirostris (Hermann) Von Heyden, 1826: 609; Thor and Willmann, 1941:167; Baker and Hoffman, 1948: 237; Baker and Wharton, 1952: 193; Meyer and Ryke, 1959: 370; Muma, 1960: 324; Shiba, 1969: 108; Hughes, 1976: 258; Kuznetsov and Livshits, 1979: 51; Tseng, 1980: 256; Gupta and Ghosh, 1980: 194; den Heyer and Sergeyenko, 2009: 61; Skvarla et al., 2014: 54.

Diagnosis

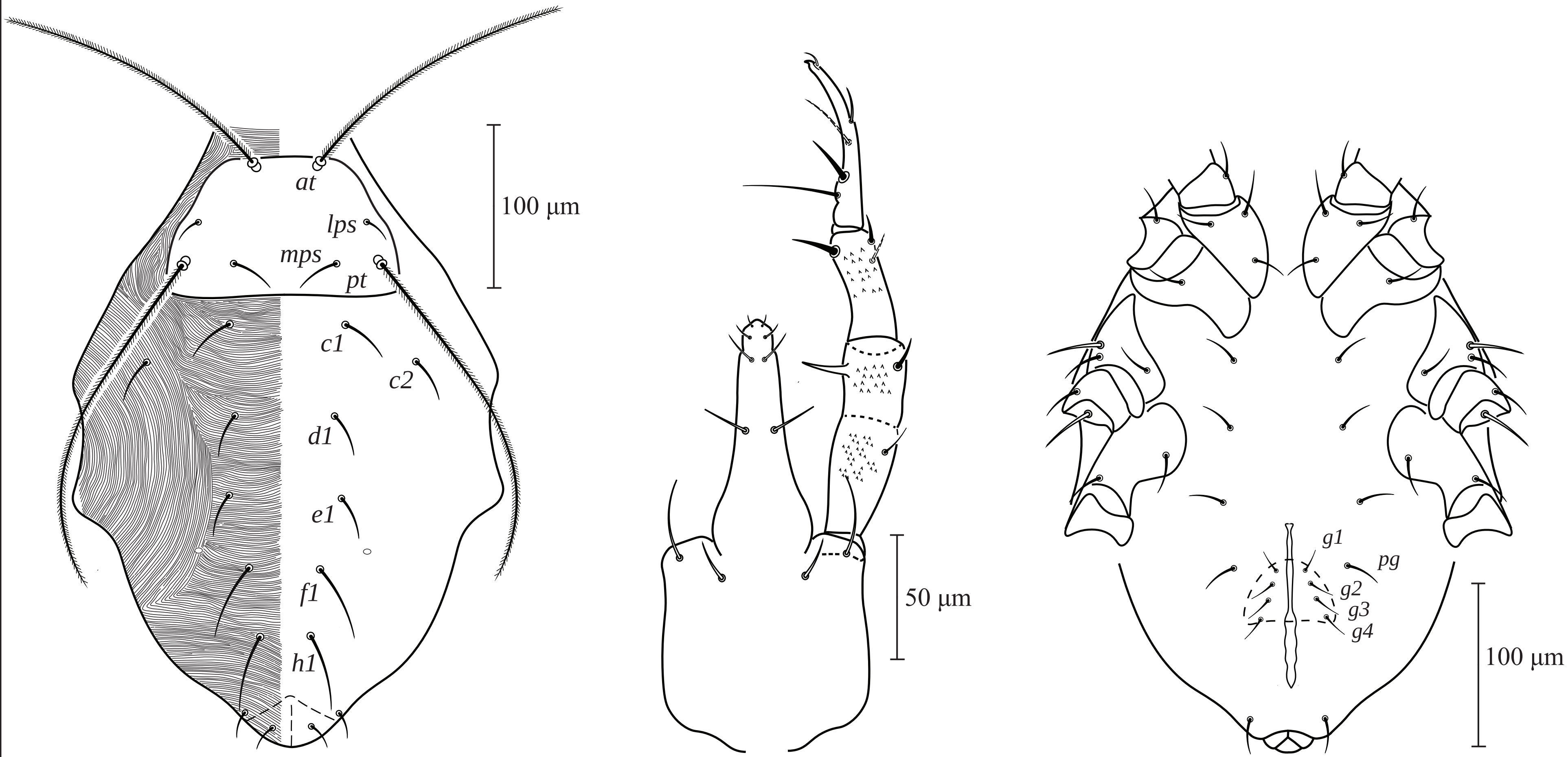
Female: Mean size of idiosoma: 381 x 250 μm. Pedipalp comprised of five segments. Palp telofemur, genu, and tibiotarsus features elongated apophyses or moderately robust spiniform setae on the inner edges. Apophysis on palpal telofemur cylindrical in appearance. Palp telofemur bears a single stout, simple tactile seta on the external surface. An articulating joint present between palp genu and tibiotarsus complex. Palp tibiotarsus bears one simple, elongated seta on the proximal inner margin, a long stout seta and two simple setae medially, and a single seta apically; tibiotarsus terminates in a small claw. Palp femur and genu densely covered with minute spike-like protrusions. Propodosomal shield devoid of striations or reticulations, features one pair of anterior trichobothria and one pair of posterior trichobothria, both significantly elongated and moderately ciliated, the posterior pair measuring nearly half the length of the idiosoma; shield also bearing one pair of lateral proterosomal setae and one pair of medial proterosomal setae. Integument densely papillated; middorsal integument marked with pronounced smooth striations; midventral integument features finely lobed striations. Leg IV longer than idiosoma. Coxal setation II–IV: 1-3-2. Pretarsi III and IV distinctly demarcated. Femora I exhibiting sparsely interrupted striations on both ventral and dorsal surfaces. Solenidiotaxy for genua I–IV: 3-1-1-1. Tarsi III and IV equipped with 23 and 18 tactile setae, respectively.

Male: Not obtained

Material examined:

- One female specimen from Kasaragod (Supplyco taluk depot- Kanhangad, 12° 18' 35" N, 75° 5' 29" E), collected from stored mustard on 04 August 2021 by Neeraj Martin.
- Two female specimen from Palakkad (Supplyco Taluk depot- Kalvakulam 10° 46' 25.51" N, 76° 40' 02.66" E), collected from stored Fenugreek on 27 July 2022 by Neeraj Martin.
- Two female specimen from Palakkad (Flour mill- Thekkenkunam 10° 47' 23.08" N, 76° 41' 39.18" E), collected from stored raw rice powder on 16 January 2023 by Neeraj Martin.

PLATE 25



Dorsum

Gnathosoma & Palp

Ventrum

Cunaxa setirostris **(Hermann, 1804), Adult female**

Genus *Scutopalus* Den Heyer, 1979

Scutopalus Den Heyer 1979a:188; Rocha et al., 2013; 40; Castro and Den Heyer, 2009: 20; Skvarla et al., 2014: 39.

Cunaxoides Shiba, 1978: 96; Kuznetzov and Livshitz, 1979:76.

Scutopalus (*Neocunaxoides*) Gupta and Ghosh, 1980: 190; Tseng 1980: 268; Smiley, 1992: 356; Corpuz-Raros, 1996:132; Lin and Zhang, 2000: 116.

***Diagnosis*:** Pedipalp composed of three parts. Palp femurogenu equipped with 5 setae; tibiotarsus elongated, bears 5 setae and features one attenuate solenidion, two-pointed process, and a terminally positioned spine like claw. Four pairs of hypostomal (*h1-h4*) and two pairs of adoral setae (*ao1-ao2*) present. Chelicera tri-segmented and asetose, infrequently possess one seta. Dorsal idiosoma features well demarcated, sclerotized proterosomal shield, bearing one pair of lateral and median proterosomal setae (*lps* and *mps*) and one pair of anterior and posterior trichobothria (*at* and *pt*). Proterosomal shield extends over propodosoma and a portion of hysterosoma, reaching approximately to the proximity of *e1*. Dorsal hysterosoma inconsistently possess a shield, confluent with proterosomal shield. Dorsal idiosoma comprises setae *c1*, *d1*, *e1*, *h1*, *c2*, and *h2*; seta *f2* absent. Genital plates striated, exhibit different levels of sclerotization, each bearing four setae; a small, accessory platelet occasionally found lateral to the genital plate. The shape of genital valves inconsistent. Coxal plates well-sclerotized; coxae I and II fused, sometimes medially coalesced or remain contiguous and demarcated; coxae III and IV confluent. Tibia III provided with a single, blunt rod-like solenidion. Tarsus I features a peg-like seta, inserted within a shallow indentation. Tibia IV equipped with a simple tactile setae accompanied by a trichobothrium. Femora divided. Ambulacral claws undulated. Coxal and basifemoral setation varies among species.

Type species: *Scutopalus latisetosus* Den Heyer, 1979

Scutopalus pradhani Gupta & Gosh, 1980

PLATE 26 A, B

Neocuaxoides pradhani Gupta and Gosh, 1980:189.

Scutopalus pradhani Den Heyer, 1979a: 187; Skvarla *et al*, 2014: 39.

Redescription

Female: Gnathosoma: Subcapitulum 142 long, complemented with two pairs of adoral setae. Four pairs of subcapitular setae (*hg1–4*) present, among which setae *hg4* distinctly longer than the remaining pairs. Palp three segmented, 102 long. Palp chaetotaxy: trochanter asetose; femurogenu with four outer and one inner setae; tibiotarsus bears one pointed process and three setae. Tibiotarsus ends in a robust claw. Chelicera broad basally, gradually tapering distally, not extending beyond base of tibiotarsus (reaching at the level of the base of tibiotarsus); movable digit sharp, dorsum of chelicera exhibits a granulated texture, featuring two dorsal setae. Dorsum: Idiosoma 324 µm long, 243 µm wide. Partially covered by a single smooth and well-defined shield, 259 long. Dorsal shield comprises one pair of lateral and medial propodosomal setae (*lps*, *mps*), one pair of anterior and posterior trichobothria (*at*, *pt*), as well as simple tactile setae *c1*-*c2*, *d1* and *e1*. Setae *f1* and *h1* placed off the shield. Setae *h2* small and placed lateral to the anal region. Dorsal setae *lps*, *mps*, *c1*-*c2*, *d1*, *e1*, *f1* simple; anterior and posterior trichobothria bear ciliations, with cilia elongating distally and narrowing terminally, giving the trichobothria a tapered appearance. Setal lengths are as follows: *at* 122, *pt* 142, *lps* 26, *mps* 25, *c1* 12, *d1* 14, *e1* 25, *f1* 30, *h1* 28, *c2* 26, and *h2* 20. Sclerites not present behind dorsal shield. Integument smooth. Cupule *im* present, positioned between dorsal setae *e1* and *f1*. Venter: Partially covered by clearly demarcated plates. Coxal plates I and II indistinctly separated medially with a slight demarcation, each plate bearing six setae; coxal plates III and IV coalesced, posterior edge extending beyond posterior edge of genital plates and with six setae each. All coxal plates adorned with compact, fine striations. Coxal setation I–IV: 3-3-4-3. Genital plates striated and faintly sclerotized, bearing four pairs of setae (*g1–g4*). Integument between the coxal and genital shields bears four pairs of setae. Anal region featuring one pair of anal setae accompanied by one pair of paranal setae. Leg lengths: Leg I 242, leg II 218, leg III 238, and leg IV 252 long. Legs exhibit a bidirectional orientation, with legs I and II pointing anteriorly while legs III and IV posteriorly aligned.

Leg chaetotaxy: trochanters I-IV, 1-1-2-1; basifemora I–IV, 2-2-3-3; telofemora I–IV, 3-3-3-2; genu I-IV, 8-7-6-6; tibia I-IV, 7+1solenidion-6+1solenidion-13+1solenidion-9+1 trichobothrium; tarsus I-IV, 14+2 solenidion-14+1 solenidion-10-10.

Male: Not obtained.

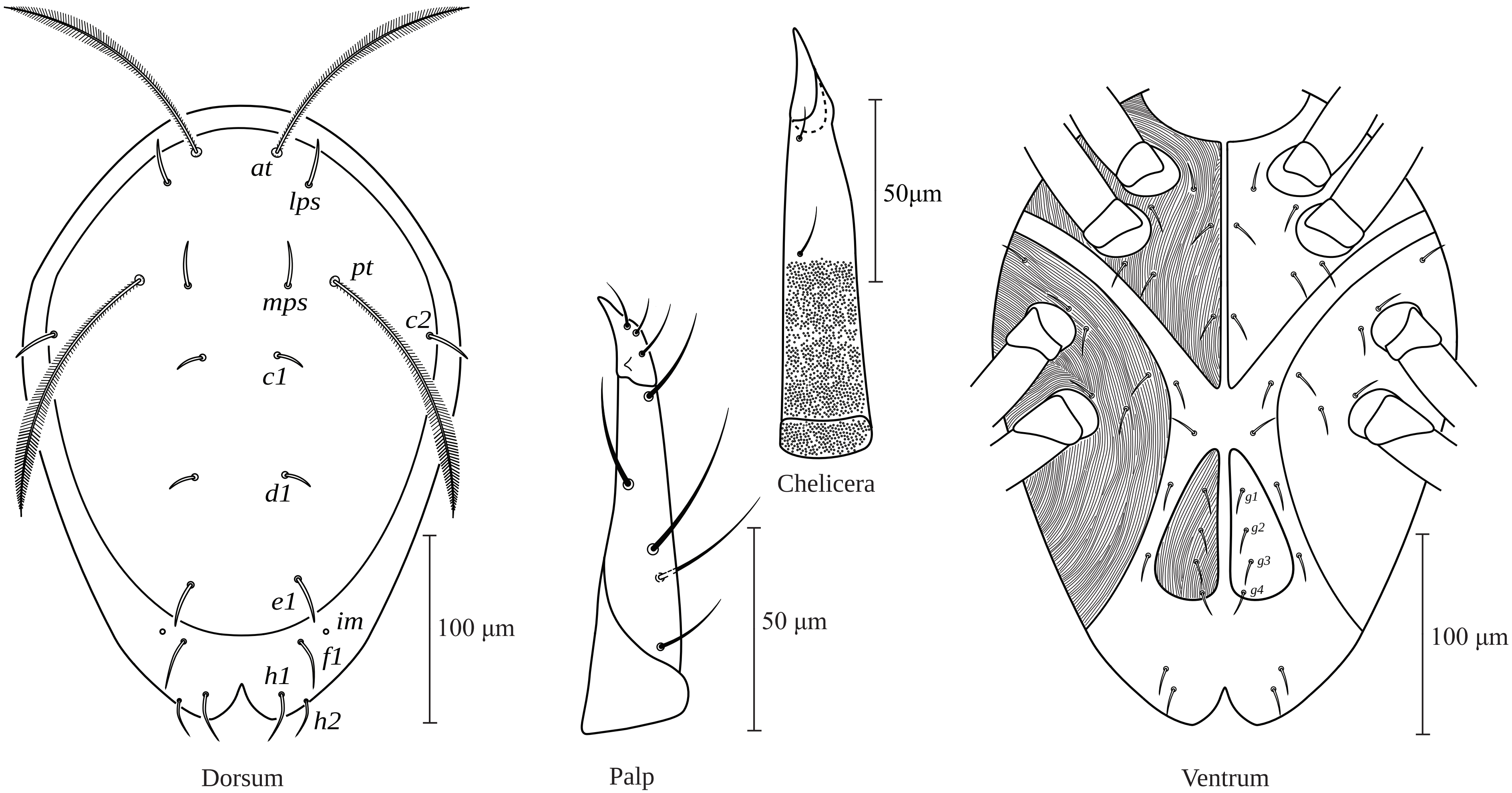
Material examined:

- One female specimen from Malappuram (Supplyco Depot- Angadippuram, 10° 58' 44.54" N, 76° 12' 27.14" E), collected from stored raw rice on 07 October 2021 by Neeraj Martin.

Remarks

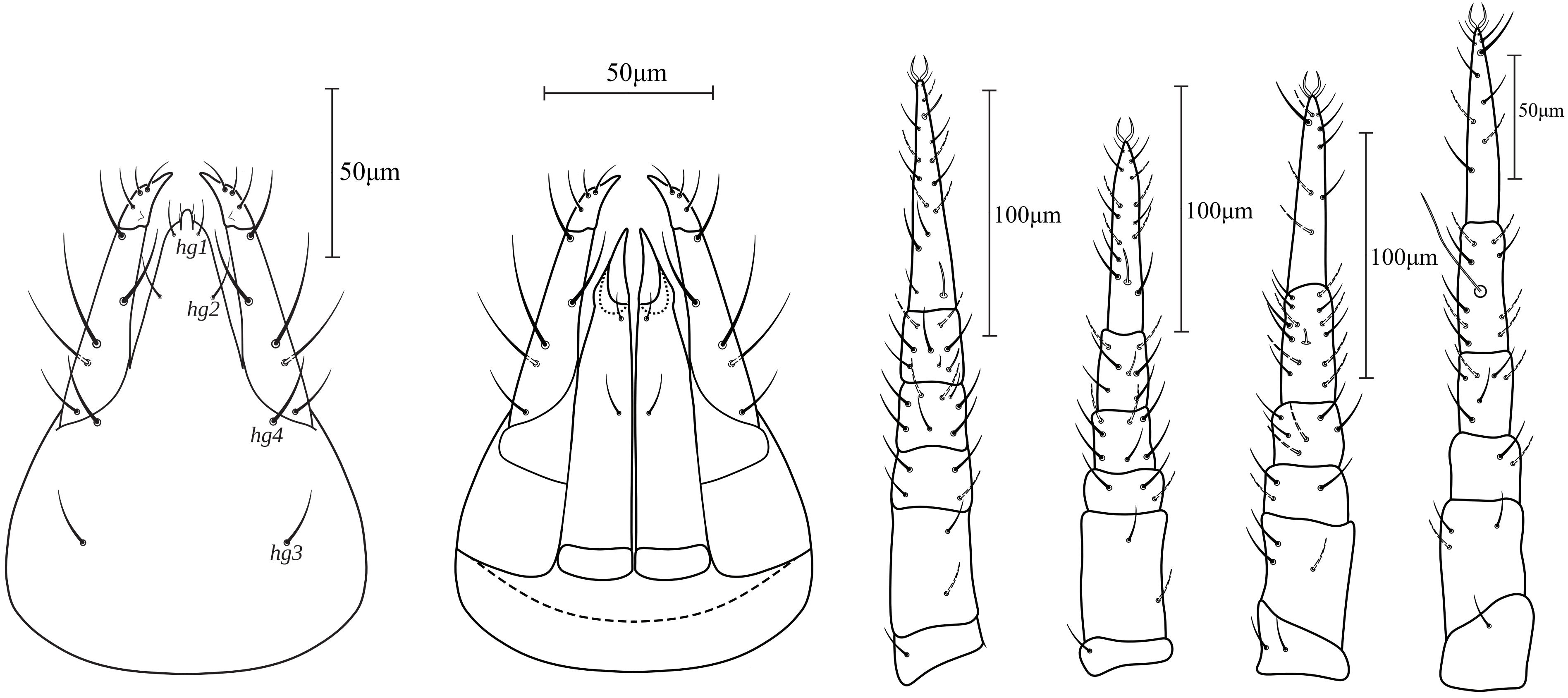
The examined specimen aligns with the morphological features of *Scutopalus pradhani* Gupta and Ghosh, 1980, confirming its identity. The original description by Gupta and Ghosh (1980) was deficient in several critical details, including the leg chaetotaxy and the number of dorsal setae. Additionally, the supporting illustrations were rendered in an incomplete manner, lacking precision. These omissions and shortcomings have been addressed and rectified in the present redescription.

PLATE 26 A



Scutopalus pradhani **Gupta & Gosh, 1980, Adult female**

PLATE 26 B



Scutopalus pradhani **Gupta & Gosh, 1980, Adult female**

4.2.3.9. Family Erythraeidae Robineau-Desvoidy, 1828

Leptides Billberg, 1820: 126.

Erythreidae Robineau-Desvoidy, 1828: 144; Oudemans, 1909: 60.

Rhyncholophides Koch, 1842: 49.

Leptoidae Agassiz, 1846: 206; 1848: 595.

Rhyncholophoidae Agassiz, 1846: 206.

Rhyncholophidae Kramer, 1877: 227.

Rhyncholophini Canestrini, 1885: 162.

Erythraeinae Oudemans, 1902: 60.

Rhyncholophinae Hull, 1918: 22.

Smarididae Southcott, 1948: 252.

Thrombidiidae Andre, 1953: 150.

Leptidae Oudemans, 1941: 178; Feider, 1954: 1017.

Balaustiidae Grandjean, 1947: 12.

Erythraeidae Southcott, 1961: 456; Beron, 2008: 58.

Diagnosis: Body displays a bright red coloration. Gnathosoma, in adult and nymphal stages, permanently affixed to anterior propodosoma, devoid of flexible collar that permits protrusion. Dorsally, a faint indentation demarcates the propodosoma from the hysterosoma. Propodosoma features a well-formed crista metopica; may extend posteriorly to the mid-point of the dorsum. Crista Metopica bears anterior and posterior sensillary regions; comprising anterior sensilla externae and posterior sensilla externae respectively, along with two pairs of setae; anterior laterals and posterior laterals. 1-2 pairs of eyes present. Palp tibia apically equipped with a robust claw. Chelicerae unsegmented, stylet-like; bear teeth distally. Bothridial sensillae not found on legs of larval stages. Lateral tarsal claws (neolateral pedal claws) on larval feet variable in size. Idiosomal setae simple in most genera. Basifemur III typically bears two normal setae. Tibia I features two solenidia (φ, ω). Palp tarsus provided with long basal setae (*nc*).

Type genus: *Erythraeus* Latreille, 1806

Genus *Balaustium* von Heyden, 1826

Balaustium von Heyden, 1826: 19; Gervais, 1844: 164; Vitzthum, 1942: 874; Enydhoven, 1944: 52; Grandjean, 1947: 3; 1947a: 327; Sellnick, 1949:130; Schweizer, 1951: 145; Willman, 1952: 168; 1954: 244; Baker and Wharton, 1952: 240; Evans and Browning, 1953: 418; Turk, 1953: 26; Cooreman, 1955: 13; 1956: 5; Southcott, 1946: 46; 1961: 543. Sellnick, 1958: 42; Meyer and Ryke, 1959a: 307; Beron, 2008: 175; Si-Yuan Xu et al., 2024: 32.

Belaustium Oudemans, Gervais, 1844: 164.

Monotrombidium Krausse, 1924: 2.

Balaustiinae Grandjean, 1947: 54.

Guatustium Haitlinger, 2000: 74.

Palenqustium Haitlinger, 2000: 80.

***Diagnosis*:** Adult and nymph: Colour in live form varies from bright red to dark red, with adults displaying more intense hues than larval or nymphal stages. A pair of eyes present comprised of single lens, positioned laterally on idiosoma. Underdeveloped or rudimentary crista metopica evident, with anterior and posterior sensillary areas bearing a pair of sensillae. Two distinct urnulae inserted anterolaterally on the dorsal idiosoma, positioned posteriorly to the eyes. Palp genu lacks distal expansion. Palp tibia normal, tapering distally. Palp odontus features a conspicuous, dentate prominence along the medial margin of its blade. Dorsal idiosomal setae exhibit setules or barbs. Larva: Cheliceral bases gracile. Galeae typical, with sparse barbules. Supracoxal setae present on palps. Palp setation (femur to tarsus): 1-2-3-6. Palpal tibial claw bears a ventrally arising additional tooth, positioned proximally. Dorsal propodosoma comprises a narrow, elongated, and weakly sclerotized scutum with faintly demarcated borders, confining a discernible crista metopica that bears anterior and posterior sensillae. Scutellar setae *AL* and *PL* present. A pair of eyes present. Pedal coxal setation: 1-1-1; trochanter setation: 3-3-2. Anterior tarsal claw arcuate, minimally ciliated. Empodium slender and elongated. Posterior tarsal claw bifurcated, comprising an anterior, bacilliform element and a shorter, arcuate posterior element bearing faint ciliation.

Type species: *Trombidium murorum* Hermann, 1804.

Balaustium murorum (Hermann, 1804)

PLATE 27

Trombidium murorum Hermann, 1804: 28.

Belaustium murorum Vitzthum, 1929: 69.

Balaustium murorum Oudemans, 1916: 46, Schweizer, 1951: 147; Schweizer and Bader, 1963: 278; Rack, 1973: 129; 1983: 157; Gabrys, 2000: 55; Halliday, 2001:327; Makol, 2010: 441; Beron, 2008: 271.

Diagnosis

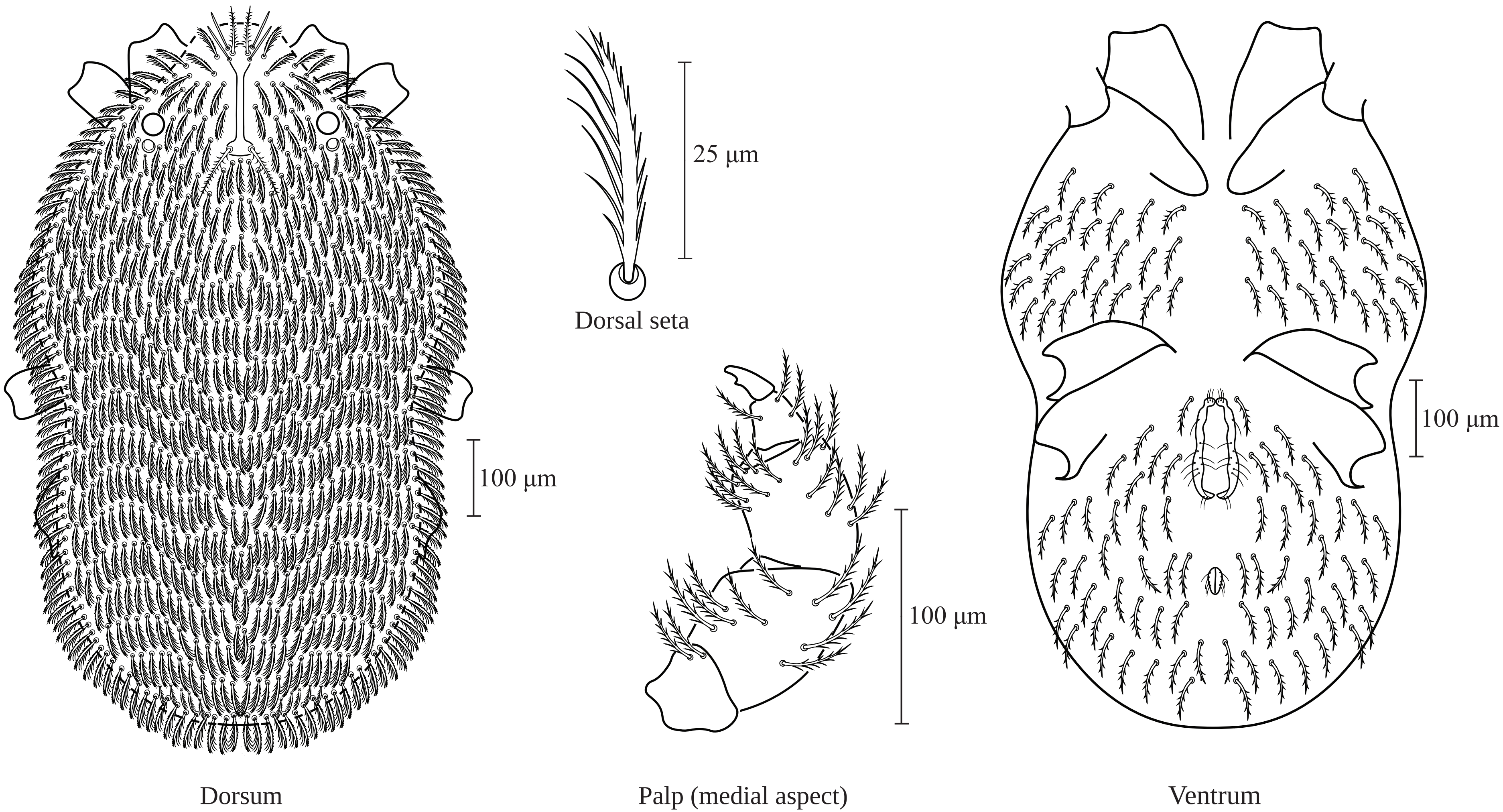
Female: Size of idiosoma: 765 x 400 µm. Idiosoma oval in shape, copiously covered with small setae, consistent in appearance. Chelicerae slender, ensiform and capable of being withdrawn into the idiosoma. Pedipalps sturdy dispersed with semi pectinate setae, with palp genu as broad as long, Palp odontus features a blunt tip and a ventral hooklet process. Palp genu equipped with up to 11 solenidia aligned dorso-laterally. Crista metopica features two sensillary areas accommodating a pair of anterior sensillary setae (*ASens*) and posterior sensillary setae (*PSens*); *PSens* are longer than *ASens* and covered with setules. Two non-sensillary setae (*AM*) positioned antero-laterally to the anterior sensillary setae, and an additional two (*AL*) aligned postero-laterally to the same. Setae *AM* and *AL* conspicuously longer than other setae in the surrounding vicinity of crista metopica. Eyes present, positioned lateral to the crista metopica, and aligned level with the *PSens*; urnulae inserted proximally posterior to the eyes. Ventral idiosomal setae narrow and terminate in sharp points. Leg IV longer than leg I to a certain extent, legs II and III shorter than leg I and IV. All leg segments exhibit diverse setal morphologies, prominently featuring brush-like setae clustered across the ventral surface of tarsi. Tarsus I comprises approximately 26 solenidia. Paired claws bearing fimbriae present at the distal end of tarsi I-IV. Modified setae cluster on femur, tibia, and tarsus of all legs, with solenidia scattered across dorsal and lateral surfaces.

Male: Not obtained.

Material examined:

- One female specimen from Palakkad (Melamuri, 10° 46' 25.25" N, 76° 38' 26.61" E) collected from stored nutmeg on 23 September 2022 by Neeraj Martin.

PLATE 27



Balaustium murorum **(Hermann, 1804), Adult female**

4.2.3.10. Family Smarididae Vitzthum, 1929

Rhyncholophides Koch, 1842: 49; Michael, 1884: 39.

Trombidiidae Murray, 1877: 117.

Rhyncholophidae Henking, 1882: 598; Berlese, 1893: 8; Thor, 1900: 3; 1900: 1; Banks, 1907: 599; George, 1907: 41; Thor, 1925: 277.

Erythraeidae Banks, 1915: 38; Miller, 1925: 109; Andre, 1927: 169; Womersley, 1934: 179; 1936: 117.

Thrombidiidae Hull, 1918: 22.

Smarididae Vitzthum, 1929: 69; Andre and Lamy, 1937: 85; Womersley and Southcott, 1941: 61; Oudemans, 1941: 179; Vitzthum. 1942: 875; Lawrence, 1944: 458; Southcott, 1946a: 173; Daniel and Samsinak, 1955: 1242; Beron, 2008: 48; Costa et al., 2021: 90.

Smarisidae Grandjean, 1943: 242; 1944: 131.

Smaridiidae Baker and Wharton, 1952: 241; Baker et al., 1956: 123; Meyer and Ryke, 1959a: 305.

Smaridae Lamb, 1952: 372.

Diagnosis: Cheliceral digits arcuate in larvae. Adult and nymphal gnathosoma features armilla; facilitate retraction from idiosoma. Leg I of larva complemented with one or more trichobothrium; if a single trichobothrium present, it typically confined to distal tarsus I; in instances of multiple occurrences, it distributed on tibia or genu, in addition to tarsus. Lateral tarsal claws typically uniform in appearance. Dorsal idiosomal setae features intricate morphology, varies among species. Idiosomal setae comprised of a pedicle and a scobillum, displaying a phylloid shape. Inflated proximal part of pedicle integrates to amphoral socket. Posterior sensilla typically filiform and tapering. Eyes positioned between anterior and posterior sensillary areas, or proximal to the posterior area. Crista metopica occasionally expand to form a prodorsal sclerite. Posterior margin of prodorsal plate convex in outline. Adult basifemur III carries 2 setae (Smaridinae excluded, only 1 present). Ventral setae *2a* normally present (*Fessonia* excluded, *2a* absent). Setae *3a* either equal in length to or exceed the length of *1a* (*Fessonia* exhibit deviation; *3a* markedly shorter). Ventral setal count posterior to coxae

III variable, ranging from 6 to 11 setae. A trichobothridial pit depressed into distal tarsus I. Palp odontus generally half or shorter relative to palp tibia. Palp tibial setae usually barbed except *Smaris* and *Fessonia*; bears one and two smooth setae, respectively.

Type genus: *Smaris* Latreille, 1796

Genus *Fessonia* von Heyden, 1826

Fessonia von Heyden, 1826: 609; Womersley and Southcott, 1941:63; Southcott, 1946a:174; Baker and Wharton, 1952: 242; Southcott, 1957: 97; Meyer and Ryke, 1959a: 322; Beron, 2008: 48.

Smaridia Berlese, 1884: 16; 1893: 84; 1894: 71; Banks 1904: 29.

Smaris Vitzthum, 1929:70; 1931: 148; Andre, 1932: 4, 882; Vitzthum, 1942: 875.

Veithia Oudemans, 1941: 182; Zhang, 2003: 1.

Aecosmaris Baker and Wharton, 1952: 242.

Pilosoma Southcott, 1961: 454.

***Diagnosis*:** Adults: Two pairs of eyes present, positioned laterally on idiosoma. Dorsal idiosoma devoid of additional sclerotized shields or plates except for scutum. Crista metopica elongated, originating from idiosomal anterior extremity and extending approximately to dorsal idiosomal midpoint. Anterior crista pole without any sensillae; anterior sensillary area situated in proximity to the crista midsection, approximately one-quarter from the idiosomal anterior pole and posterior to eye level. Larva: Palp odontus exhibits bifurcation. Oral and hypostomal setae spine-like; oral setae notably shorter. Dorsal scutum trapezoidal or hexagonal in shape, bears two pairs of sensillary and two pairs of non-sensillary setae. Legs comparatively short; elongated in post larval instars. Each coxa features one serrated seta. Ventral intercoxal area bears setae *1a*, *2a*, and *3a*. Trichobothrial sensillae absent on genu I. Tibia I equipped with one unpaired trichobothrial sensillum. Tarsus I possess a compound depressed pit with sensillum and spatulate seta, along with two posterior trichobothrial sensillae. Trichobothria absent on the legs of post-larval active instars. Proximal eupathidium and famulus on tarsus I exhibit incomplete or improper development. Lateral claws on tarsi I-III bursiform, multisetulose ventrally, and hook-less. Empodium falciform provided with small setules.

Type species: *Trombidium papillosum* Hermann, 1804

Fessonia indica Martin and James, 2024

PLATE 28 A, B

Fessonia indica Martin and James, 2023: 305-312

Description

Post larval instar: Dorsum**:** Idiosoma 518 (620) long, 258 (308) wide. crista metopica approaches the mid-idiosoma but terminates before attaining the level of the leg III bases. Anterior sensillary area located posteromedially relative to the two pairs of eyes, positioned 94 (112) from the anterior tip of propodosoma, with a single seta, 16 (19) long (normal dorsal setae). Anterior sensilla ciliated, 46 (55) long; bases 7 (8) apart. Posterior sensilla ciliated, 41 (49) long, 40 (47) away from anterior one and bases 15 (17) apart. Two pairs of eyes, differing in size present; the anterior eyes 20 (24) in diameter, the posterior eyes, positioned slightly posterolateral to the anterior pair, measure 14 (17). Dorsal setae densely arranged, broader, dorsally convex with flattened ventral surface, 18 (21) long, bearing 6-8 lines of serrations extends longitudinally to the pedicel of the seta. Distance between anterior sensillary area to posterior sensillary area 12.95.

Ventrum: ventral setae with dense ciliations (lanceolate pattern), setae 13-22 (15-26) long. Genital pore without any surrounding setae.

Legs: legs covered with elongated and tapering spiculated setae from coxae to tarsus. Specialized setae distributed on telofemur, genu, tibiae and tarsi. Measurements of leg I: coxa 77 (92), trochanter 53 (64), basifemur 90 (108), telofemur 111 (134), genu 151 (181), tibia 152 (181), tarsus 163 (195). leg II: coxa 81(96), trochanter 44 (53), basifemur 45 (54), telofemur 65 (78), genu 81 (97), tibia 102 (122), tarsus 62 (74). Leg III: coxa 80 (96), trochanter 62 (74), basifemur 57 (68), telofemur 70 (83), genu 94 (112), tibia 117 (140), tarsus 71 (85). Leg IV: coxa 75 (89), trochanter 56 (67), basifemur 60 (72), telofemur 107 (128), genu 124 (148), tibia 134 (160), tarsus 91 (109). All tarsi terminated with paired claws. Leg chaetotaxy as follows, Leg I: 1-9-22-21+1 specialized seta-30+1 specialized seta -36+2 specialized setae-67+2 specialized setae, 1 ζ; Leg II: 1-7-8-14-20+1 specialized setae-15+2 specialized seta-27, 1 ζ; Leg III: 1-7-9-14-20-21+2 specialized setae-24+2 specialized setae, 1 ζ; Leg IV: 1-8-9-18-19+1 specialized setae-23+3 specialized setae-22+3 specialized setae, 1 ζ.

Gnathosoma**:** 110 (131) long, retractable. Chelicerae 55 (65) long. Cheliceral digits short, 4 (5) long. Gnathosoma dorsally features a pair of smooth, pointed adoral setae (*cs*) 9 (11) anteriorly, and the ventral region bears a pair of smooth, pointed tritorostral setae (*bs*) 23 (27) as well as oral setae (*as*) 18 (23). Palp trochanter 17 (20) long with 1 seta. Palp femur 45 (54) long with four long dorsal setae and one ventral seta, length ranges from 12 to 25 (14 to 30). Palp genu 25 (30) long bearing four dorsal setae, and two ventral setae. Palp tibia features four setae. Odontus not bifurcated 21 (25) long. All setae arise from palp femur to palp tibia exhibiting similar morphology with leg setae. Palp tarsus 15 (18) long with four smooth setae *gc* 7 (8), *ds* 5 (4), *hc* 9 (11), *nc* 20 (24) one solenidion (ω) and two prominent distal eupathidium (ζ).

Larval and adult stages: Not obtained.

Material examined

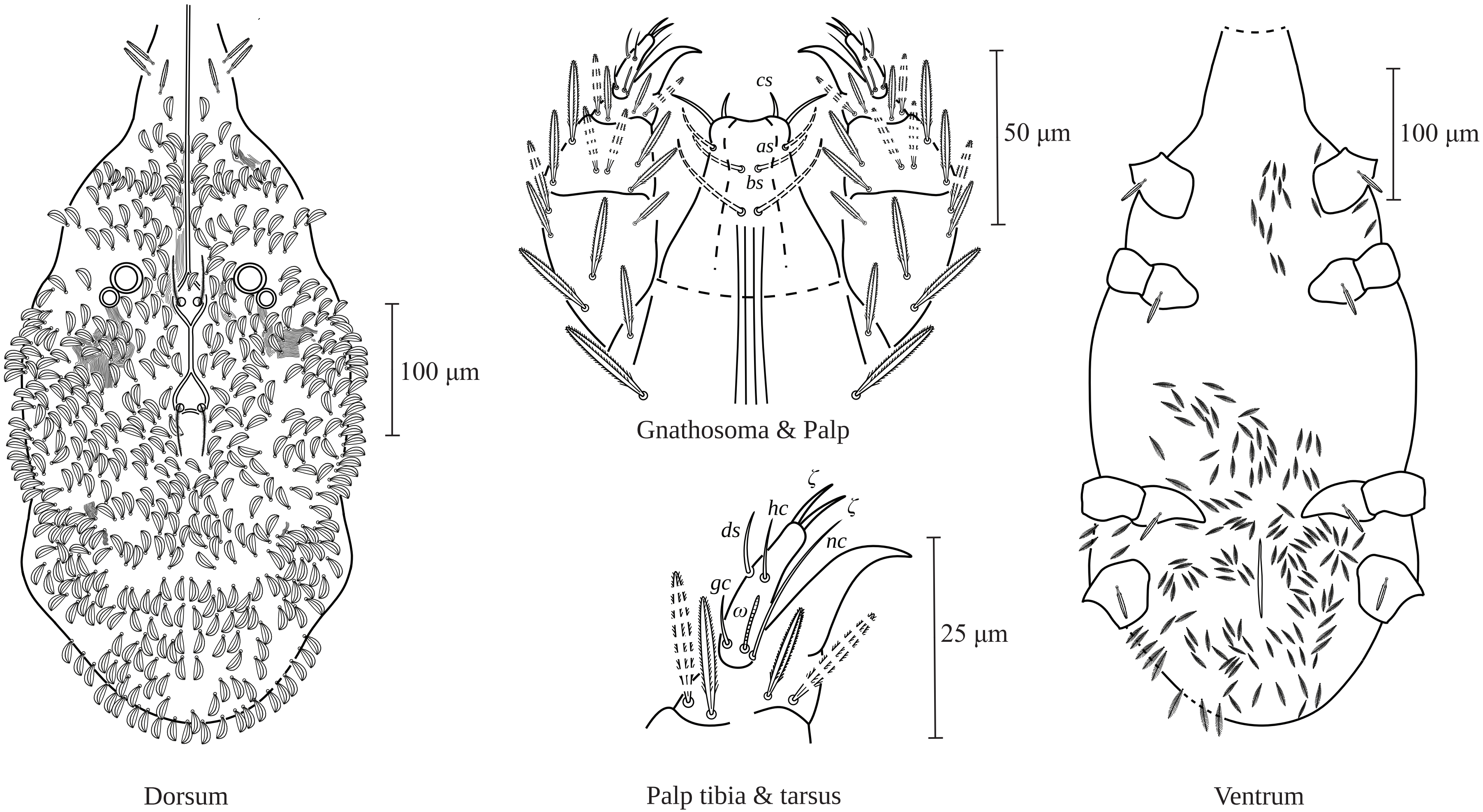
Post larval instar holotype (ZSI/WGRC/I.R.INV.25577) and one post larval instar paratype (ZSI/WGRC/I.R.INV.25578) were collected from raw rice from Kasaragod district (Food Corporation of India warehouse-Nileshwar, 12° 15' 27.84" N, 75° 08' 05.60" E) on 19th November 2020 by Neeraj Martin. The specimens were deposited at the Western Ghat Field Research Centre, Zoological Survey of India, Kozhikode, Kerala, India.

Remarks

The presence of trichobothria is developmentally limited to the legs of the larval stage in Smarididae; they are absent in post-larval active instars (Grandjean, 1947). The distinctive characteristics that set *F. indica* apart from other species within the genus *Fessonia* include the quantitative differentiation in the number of setae on tarsi I and the remarkable presence of solenidion-like specialized setae on legs I-IV in post-larval active instars. Furthermore, *F. indica* can be easily differentiated from other known species within the genus *Fessonia* due to its exceptionally short distance between ASA and PSA. The only other known *Fessonia* species in India are *F. australiensis* Southcott, 1946 and *F. assmuthi* Oudemans, 1941. *F. indica* can be discerned from other extant species within the genus *Fessonia*, with the exception of *F. australiensis* and *F. assmuthi*, by the distinct morphological features exhibited by its dorsal setae. *F. indica* shares certain morphological features with *F. australiensis* and *F. assmuthi* but exhibits significant differences. Same type of dorsal setae is present on *F. indica* and *F. australiensis*. In *F. assmuthi*, there is a consistent reduction in the length of leg setae along the distal axis, exemplified by a decrease from 50 μm on the trochanter to 30 μm on the tibia.

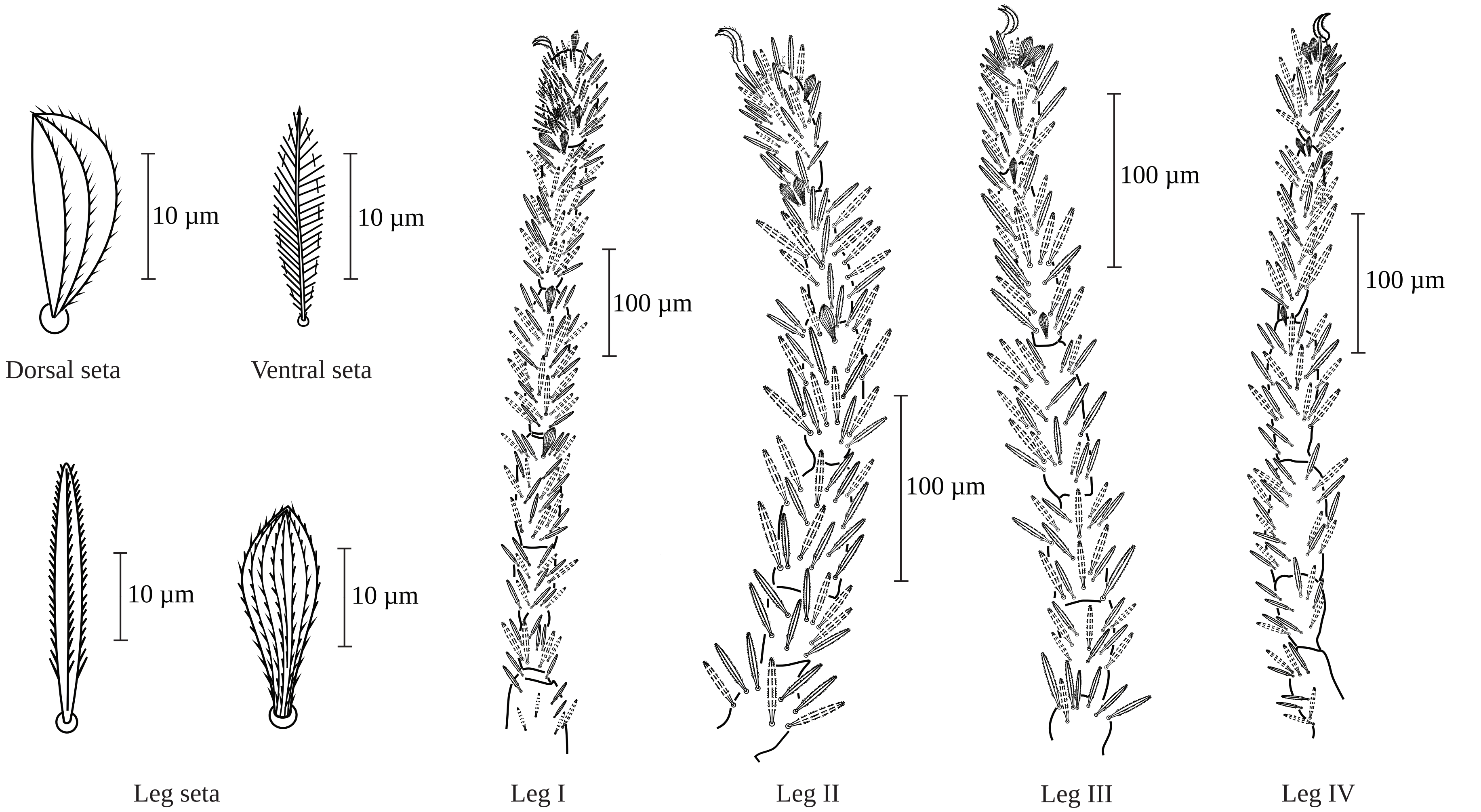
Conversely, no discernible variation in leg setal length is observed in *F. indica*. indica. In *F. australiensis*, the anterior sensillary area features two setae, while in *F. indica*, only one seta is observed. The ventral setae of *F. indica* are densely ciliated in a lanceolate pattern. The ratio between the length of idiosoma (from the tip of naso to the posterior end of opisthosoma) and the distance between ASA to PSA is 12.95 in *F. indica*, whereas it is 5.82 and 4.16 in *F. australiensis* and *F. assmuthi* respectively. The ratio between the length of leg I and the length of idiosoma is 1.29 in *F. assmuthi* and 1.53 in *F. indica*. *F. indica* is distinctive from *F. papillosa* due to the presence of two palp tarsus eupathidia (three in *F. papillosa*). Furthermore, in *F. papillosa*, the palp odontus exhibits bifurcation, whereas in *F. indica*, it remains non-bifurcated. In comparison with *F. torshizica*, a key distinguishing feature is the bifid shape of the palp odontus. Additionally, *F. indica* can be distinguished from both *F. torshizica* and *F. papillosa* by the distinct number of setae on the palp tibia, with *F. indica* having four setae, whereas *F. torshizica* and *F. papillosa* have three setae each on the palp tibia.

PLATE 28 A



Fessonia indica **Martin & James 2024, Post larval instar**

PLATE 28 B



Fessonia indica **Martin & James 2024, Post larval instar**

4.2.3.11. Family Caligonellidae Grandjean, 1944

Caligonellidae Grandjean, 1944: 105; Berlese, 1910: 206; Willmann, 1952: 162; Summers and Schlinger, 1955; 541; Meyer and Ueckermann, 1989: 16; Fan and Li, 1995: 323,324; Fan, 2000: 422; Shoker et al., 2001: 128; Doğan, 2003: 64; Ueckermann et al., 2010: 243; Ahaniazad and Bagheri, 2012: 373; Bagheri et al., 2013: 632; Hoseini et al., 2014: 473; Silva et al., 2017: 477; Akyol, 2018: 2339; Beron 2020: 21; Akyol 2021: 43; Khaustov 2021: 910; Akyol 2023: 1835; Uğurlu et al., 2023: 1811; Mirza et al., 2025: 1.

Raphignathidae Baker and Wharton, 1952: 400.

***Diagnosis*:** Stylate chelicerae with inflated basal segments fused along midline, forming a conical stylophore. Peritremes sinuous, confined to dorsal surface of stylophore, exhibiting marked positional variability, extending along or directly to stylophore base and lateral margins, or forming transverse loops to lateral margins. Peritrematal terminations diverse, occurring either medially on inflated portion of stylophore or on outer stylophore margins. Idiosoma elongate, discoid to ellipsoidal or pyriform in shape. Pedipalp five segmented, bearing a prominent palp tibial claw. Palp tarsus elongated and cylindrical in shape with a minimum length equivalent to tibial claw and originating from the distal portion of palp tibia, featuring apically stout, specialized setae with simple, unbranched morphology. Idiosomal integument with fine striations, devoid of sclerotization or bears dorsal plates. Eyes absent or comprising up to two pairs. Legs subequal to or exceeding idiosomal length. Coxae I-II and III-IV appressed to each other, but not contiguous or confluent. Pretarsi equipped with two claws and falciform empodia, each producing multiple pairs of capitate tenent hairs arranged in a divaricate pattern. Anal aperture positioned either terminally or subdorsally; females with longitudinal aperture. Tarsus I and II bears 1-2 solenidia at its base.

Type genus: *Caligonella* Berlese 1910

Genus *Paraneognathus* Fan, 2000

Paraneognathus Fan, 2000: 423; Ardeshir et al., 2014: 146; Bagheri et al., 2015: 330: Çobanoğlu et al., 2021: 165.

Sinognathus Fan and Li, 1995: 326.

***Diagnosis*:** Males possess a linguiform process positioned ventrally on femur III. Dorsal idiosoma features 11 pairs of setae; devoid of propodosomal or hysterosomal shields. Eyes are absent. Palp femur with two setae. Stylophore distinctly elongated and conical, narrowing distally toward the bifurcated extremity. Peritremes bound exclusively to the stylophore and exhibit a horizontal crescent shape with a central emargination. The outer arms of peritremes typically display pronounced curvature in their distal segments; innermost arms markedly reduced. Ventral idiosoma marked with striations. Genital and anal pores contiguous or closely approximated, each provided with three pairs of setae. Four pairs of aggenital setae (*ag1-4*) situated on genito-anal region. In males, genital and anal pores positioned on dorsal surface. Tarsus I bears a peg-like solenidion, which varies in length, ranging from elongate to shortened. Tarsus III inconsistently possess solenidion. Femur I and genu I each typically features six to seven setae.

Type species: *Sinognathus wangae* Fan & Li, 1995

Paraneognathus wangae (Fan & Li, 1995)

PLATE 29

Sinognathus wangae Fan and Li, 1995: 326

Paraneognathus wangae Ardeshir et al., 2014: 147.

Diagnosis

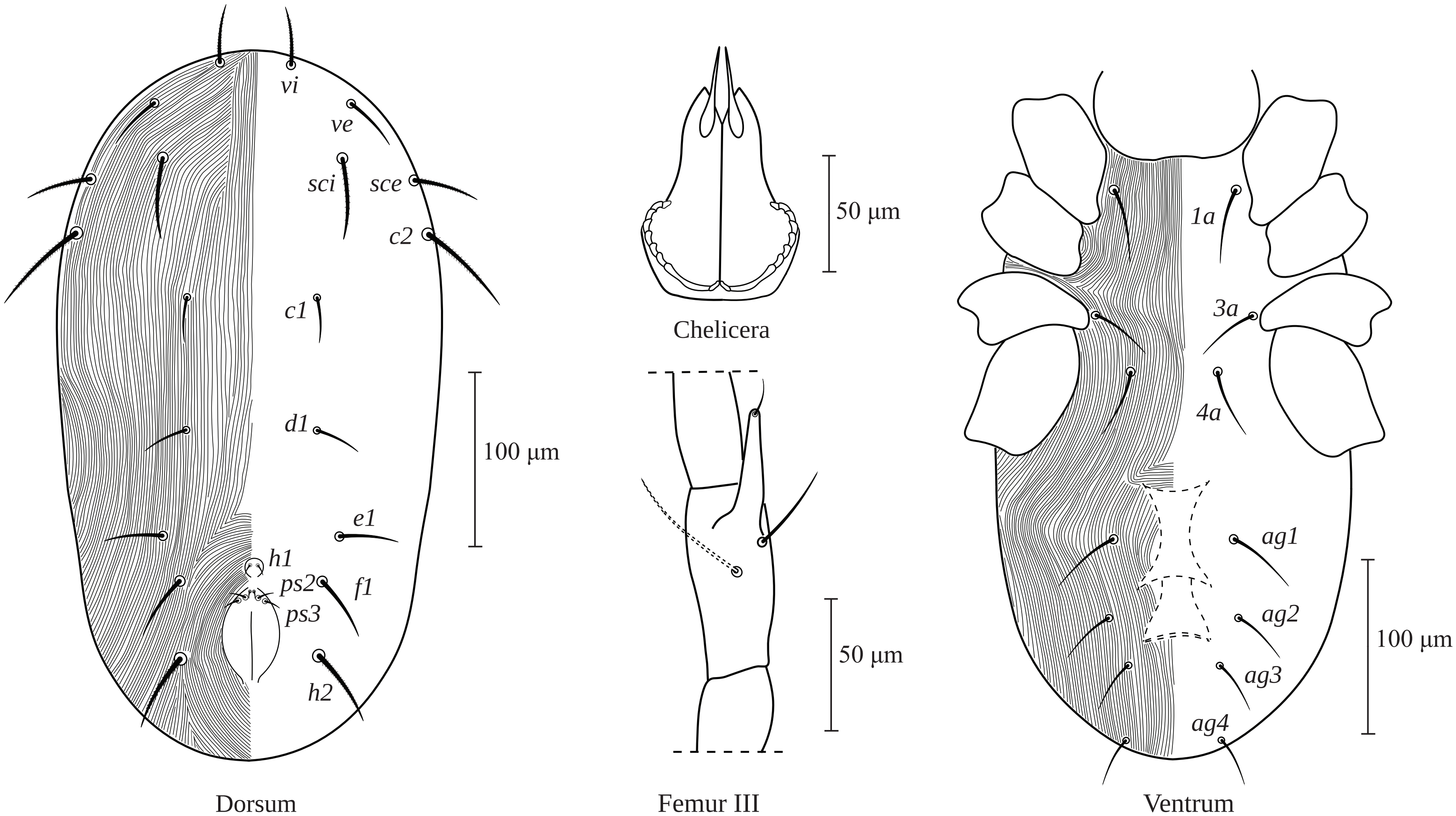
Male: Mean size of idiosoma: 410 x 220 µm. Dorsum devoid of shields and eyes, adorned with uninterrupted smooth striae, predominantly longitudinal, and transverse towards the posterior hysterosoma. Dorsal idiosomal setae features inconspicuous barbs along their length; the prodorsal setae *sci* and *c2* along with the opisthonotal setae *h2* prominently elongated than remaining dorsal setae. Genito-anal pore positioned dorsally and comprises three pairs of pseudanal setae. Ventral idiosoma striated, lacks endopodal shields between intercoxal space; setae *1a* and *3a* positioned on smooth integument instead of originating from coxae. Ventral surface complemented with four pairs of aggenital setae (*ag1–ag4*) posteriorly. Subcapitulum bears four pairs of setae (*or1*, *or2*, *m* and *n*). Peritreme ω-shaped, confined to conical shaped stylophore, featuring nine segments arranged symmetrically and three distal segments of the outermost arms exhibit a pronounced curvature. Coxae I-IV bear two setae. Tarsi I-II equipped with two solenidia (*ω*), and tarsi III possess one solenidion (*ω*). Femur III with three setae and features a conspicuous linguiform protuberance or flange ventrally, which apically bears a small, slender seta.

Female: Not obtained

Material examined:

- Three female specimen from Wayanad (Supplyco PDS depot- Bathery, 11° 39' 13.51" N, 76° 15' 28.07" E), collected from stored cowpea on 03 April 2019 by Neeraj Martin.
- Two female specimen from Wayanad (Spice store- Meppadi 11° 33' 24.5" N, 76° 07' 53.23" E), collected from stored cashew nuts on 16 April 2019 by Neeraj Martin.

PLATE 29



Paraneognathus wangae **(Fan & Li, 1995), Adult male**

4.2.3.12. Family Raphignathidae Kramer, 1877

Acheleopsis Willmann, 1951: 141.

Neoraphignathus Smiley and Moser, 1968: 315.

Raphignathus Dugès, 1834: 15.

Raphignathidae Kramer, 1877: 215; Mitra and Mitra, 1953: 430; Meyer and Ryke, 1960: 212; Atyeo et al., 1961: 15; Athias-Henriot, 1961a: 2; Atyeo, 1963a: 174; Shiba, 1969: 172; Robaux, 1976: 506; Kuznetsov, 1976: 39; Zaher and Gomaa 1979: 199; Smith-Meyer and Ueckermann, 1989: 8; Fan and Yin, 2000: 85; Fan and Zhang, 2005: 33; Bagheri et al., 2013a: 482; Beron, 2020: 119.

Diagnosis: Gnathosoma extending anteriorly surpassing prodorsum. Chelicerae cone shaped, coalesced proximally, divided distally; a pair of simple peritremes situated on cheliceral base, extending rearward to anterior margin of prodorsum. Palps robust, not elongated; usually devoid of tibial claws (reduced if present). Palp tarsus features 4 distinct eupathidia along with 4 setae. Palp coxa bear a single external lateral clavate process; trochanter lacks setae. Palp femur equipped with 2-3 setae, genu with 2 setae, (occasionally 1), and tibia bears 3 setae. Idiosoma oval shaped. Prodorsum features two pairs of vertical setae and two pairs of scapular setae. Eyes present; postocular bodies (*pob*) variably present. Dorsal hysterosoma features five series of setae (*c*, *d*, *e*, *f*, and *h*), excluding pseudanal setae occurs on anal valve. Males exhibits slightly coalesced dorsal shields; bears genital and anal openings along with a complex aedeagus. Ventrum features setae *4a* and two pairs of aggenital setae. Genital valves bear 3 pairs of setae; anal valves provided with 3 pairs of pseudanal setae. Leg chaetotaxy: coxae I 2+1 *elcp*, II 1-2, III-IV 2; trochanters I-II 1, III 2, IV 1; femora I 6, II 4-6, III-IV 3-4; genua I-II 5, III-IV 4; tibiae I-III 5, IV 3-4; tarsi I 19, II 15-17, III 13, IV 12-13. Solenidiotaxy: genua I-II 1, tibiae I 1-2, II-IV 1, tarsi I 2, II 1, III-IV 0-1. Males features enlarged solenidia *ω* on tarsi I-IV. Tarsal claws present; empodium with two rows of tenent hairs, devoid of shaft.

Type genus: *Raphignathus* Dugès, 1834

Genus *Raphignathus* Dugés, 1834

Raphignathus Dugés, 1833: 206; Atyeo et al., 1961: 14; Fan and Zhang, 2005: 33; Beron, 2020: 120.

Acheles Oudemans, 1903: 101.

Syncaligus Berlese, 1910: 202; Oudemans, 1923a: 138.

Diagnosis: Dorsal idiosoma predominantly exhibits three or occasionally four shields, comprising one pair of lateral podosomal shields and a single large hysterosomal shield. Lateral podonotal plates bear one pair of eyes. Interscutal membrane features 0-5 pairs of setae. Posterior podonotal region inconsistently exhibit two small supplementary plates. Number and arrangement of setae on dorsal idiosomal shields and interscutal membrane varies among species. Simple peritremata arise from posterior stylophore cleft, ceasing at cervical membrane, positioned at anterolateral borders of idiosoma. Palp trochanter acetose; palp femur bears 1-3 setae; palp genu equipped with 1-2 two setae; palp tibia features 3 setae and 1 tibial claw; palp tarsus provided with four setae, 1 solenidion ω and 4 terminal eupathidia. Coxae I-IV on either side of the body form a contiguous group due to close apposition. Chaetotaxy of legs I-IV (including solenidia and excluding coxal setae *1a*, *3a* and *4a*): Leg I- Coxa: 2+1elcp, Trochanter: 1, Femur: 6, Genu: 5+1κ, Tibia: 5+1-2ϕ, Tarsus: 19+1ω+1ωp. Leg II- Coxa: 1-2, Trochanter: 1, Femur: 4-6, Genu: 5+1κ, Tibia: 5+1ϕ, Tarsus: 15-17+1ω. Leg III- Coxa: 2, Trochanter: 2, Femur: 3-4, Genu: 4, Tibia: 5+1ϕp, Tarsus: 13+ 0-1ω. Leg IV- Coxa: 1, Trochanter: 1, Femur: 2-4, Genu: 4, Tibia: 3-4+1ϕp, Tarsus: 12-13+0-1ω. Males possess markedly enlarged tarsal solenidion ω.

Type species: *Raphignathus ruberrimus* Dugés, 1834.

Raphignathus neocardinalis Atyeo, 1963

PLATE 30

Raphignathus neocardinalis Atyeo, 1963a: 184; Nasrollahi et al., 2018: 2076; Khan et al., 2023: 173.

Redescription

Female: Gnathosoma: Subcapitulum 94 long comprises two pairs of subcapitular setae, *m* 48, *n* 52 and two pairs of adoral setae *or1* 19, *or2* 22. Palp five segmented, 132 long. Palp chaetotaxy (including solenidiotaxy) from trochanter to tarsus: 0-3-2-3+1claw- 4+1*ω* +4 eupathidia. Palp tarsus solenidion *ω* 9 long. Chelicerae 56 long. Dorsal anterior surface of stylophore marked with delicate broken striae. Peritremes confined basally within the stylophore. Dorsal idiosoma: 472 long (including gnathosoma) and 244 wide. A large, distinctly demarcated anteromedian shield, separated from the large anterolateral shields by a narrow band of striae. Hysterosomal shield originates between the internal humeral and internal dorsal setae. Median shield 144 long, complemented with three pairs of setae (*v1*, *v2*, and *c1*), while the lateral shields possess three pairs of setae (*sc1*, *sc2*, and *c2*), one pair of cupules (*ia*), and one pair of eyes. Interscutal membrane, devoid of setae, appears as a pair of small, almond-shaped plates positioned posterior to the prodorsal shields. Hysterosomal shield equipped with five pairs of setae (*d1*, *e1*, *f1*, *h1*, and *h2*) along with one pair of cupules (*im*). Dorsal setae simple. Lengths of dorsal setae: *v1* 36, *v2* 39, *sc1* 40, *sc2* 33, *c1* 38, *c*2 36, *d1* 36, *e1* 36, *f1* 36, *h1* 32, *h2* 30. Distances between dorsal setae: *v1–v1* 36, *v2–v2* 58, *sc1–sc1* 169, *sc2–sc2* 211, *c1–c1* 21, *c2–c2* 184, *d1–d1* 64, *e1–e1* 107, *f1–f1* 117, *h1–h1* 38, *h2–h2* 60, *v1–v2* 32, *v2–sc1* 64, *sc1–sc2* 38, *c1–c*2 106, *c1–d1* 47, *d1–e1* 62, *e1–f1* 49, *f1–h1* 36, *h1–h2* 30. Setae *e1* shorter than distance *e1–f1*. Ventrum: Ventral integument delicately striated (pattern not clearly discernible). Length of ventral setae: *1a* 38, *1b* 37, *1c* 34, *2b* 29, *2c* 28, *3a* 32, *3b* 32, *3c* 32, *4a* 36, *4c* 33, *ag1* 31, *ag2* 22, *ag3* 24, *g1*23, *g2* 22, *g3* 20, *h3* 30, *ps1* 23, *ps2* 36, *ps3* 24. Aggenital plate bears two pairs of setae (*ag1-2*); genital plate features three pairs of setae (*g1-3*); pseudo-anal setae (*ps1-3*) present. Leg lengths: leg I 235; leg II 239; leg III 272, leg IV 332. Leg chaetotaxy (including solenidiotaxy) I-IV: coxae 2-2-2-1; trochanters 1-1-2-1; femora 6-5-4-4; genua 5(+*κ*)-5(+*κ*)-3-4; tibiae 5(+*φ*, +*φp*)-5(+*φp*)-5(+*φp*)-4(+*φp*); tarsi 16(+*ω1*+*ω2*)-12(+*ω*)-12(+*ω*)-12(+*ω*).; tarsus IV features one solenidion (*ω*).

Male: Not obtained

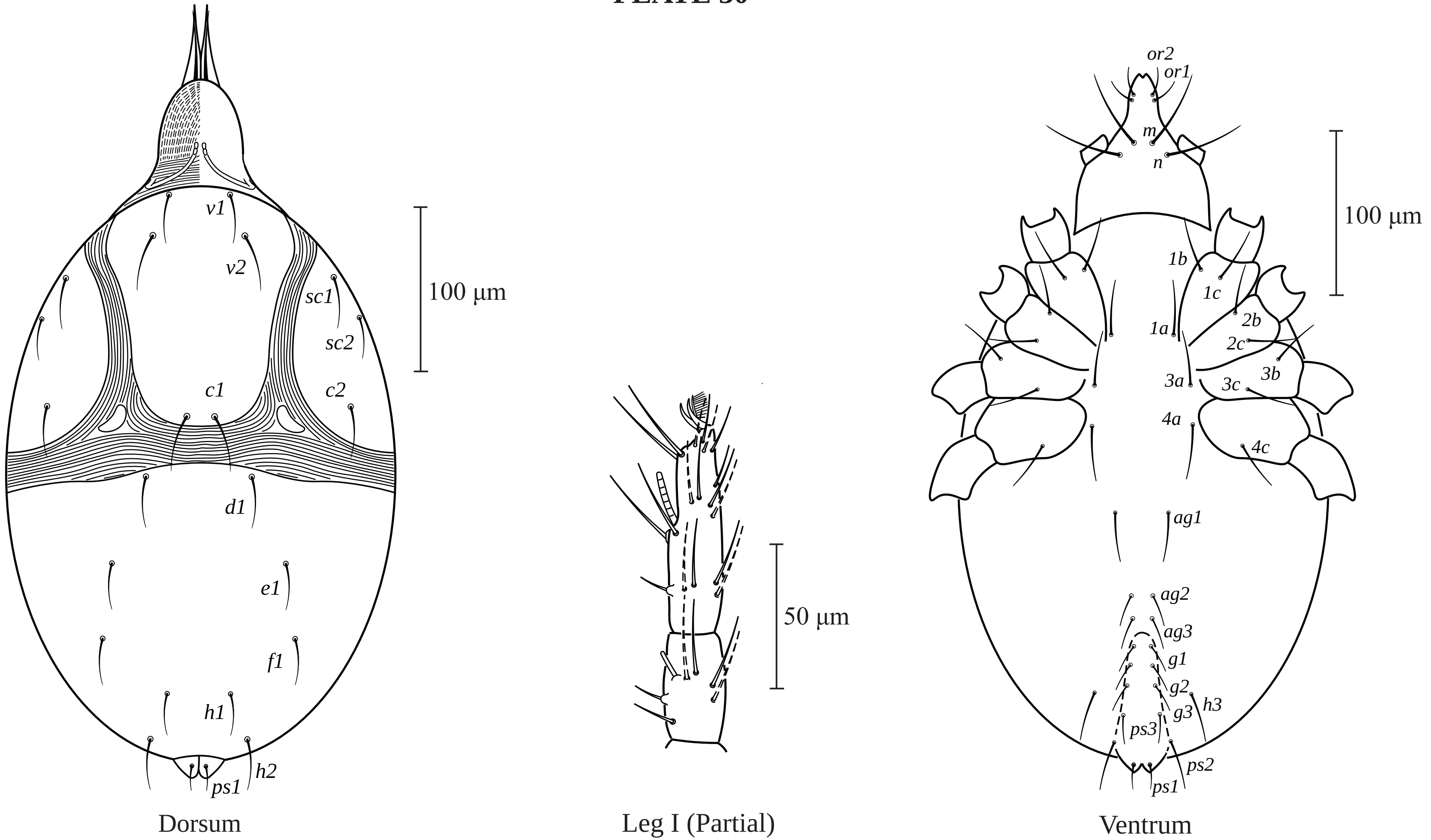
Material examined:

- One female specimen from Kasaragod (Supplyco store- Manjeshwar, 12° 43' 30.08" N, 74° 53' 08.05" E), collected from stored dried chilly on 10 February 2021 by Neeraj Martin.

Remarks

The morphological characteristics of the examined specimen are consistent with those of *Raphignathus neocardinalis* Atyeo, 1963a, confirming its identification. The original description by Atyeo (1963a) was incomplete, particularly regarding the chaetotaxy of the legs, the details and measurements of the dorsal and ventral setae, as well as the details of the subcapitular setae. The illustrations of the ventrum were absent. These omissions and shortcomings have been addressed and rectified in the present redescription.

PLATE 30



Raphignathus neocardinalis **Atyeo, 1963, Adult female**

4.2.3.13. Family Stigmaeidae Oudemans, 1931

Stigmaeidae Oudemans, 1931: 252; Canestrini and Fanzago, 1876: 132; Canestrini, 1886: 181; Ewing, 1909: 402; Berlese, 1910: 201; Halbert, 1919: 112; Hirst, 1925: 1023; Thor, 1930: 99; Gerson, 1972: 321; Chaudhri et al., 1974: 250; Wood, 1964: 580; Meyer and Ryke, 1960: 210; Summers, 1960: 235; 1966: 232; Wood, 1981: 370; Wang, 1981: 82; Barilo, 1987: 1096; Ueckermann and Meyer, 1987: 380; 1988: 34; Gupta and David, 1990: 281; Gupta, 1991: 209; Ehara, 1993: 80; Hu and Chen, 1994: 43; Rimando and Corpuz-Raros, 1996: 142; Fan et al., 1997: 140; Fan and Walter, 2004: 78; 2005: 22; Fan, 2005: 38; Fan and Chen, 2010: 122; Doğan, 2003: 381; Fan et al., 2016: 4; Beron, 2020: 140.

Raphignathidae Baker and Wharton, 1952: 66.

Diagnosis: Gnathosoma fixed in position, lacking retractability; not concealed by prodorsum. Palptibia equipped with a prominent or reduced claw; variable in form, occasionally features a diminutive accessory claw; palptarsus exhibit a short process. Nearly all setae on palptarsus terminally trifurcated. Tracheal system confined to proximal area of chelicerae, devoid of stigmata or peritreme. Chelicerae needle-like; coalesced or divided. Palpus five segmented. Palp genu exhibit one or two setae. Palp tarsal eupathedia vary in forms; may remain divided, fused, or appear trident shaped. Subcapitular bears two setae. Idiosoma sclerotized, feature one or more plates, either striated or smooth; lyrifissures absent. Integrity of prodorsal and opisthodorsal shields variable; partitioned or coalesced, sometimes featuring a distinct suture. Prodorsal setae *sci* sometimes present and positioned between *ve* and *sce*. Hysterosoma occasionally exhibit transverse shields. Distribution of hysterosomal setae *e1* and *e2* variable in females; positioned either on same shield or separate platelets. Paragenital setae situated on distinct genital plates. externally sealed by an anogenital cover. Coxal plates I-II well demarcated and distinctly spaced from III-IV. Legs moderately long. Coxa II provided with one or two setae. Tarsal claws prominent, presence of arolium variable. Coxisternal shields and setal arrangements on prodorsum and opisthodorsum differs across genera; some exhibit enlarged humeral shields coalesced to coxisternal shields

Type genus: *Stigmaeus* Koch, 1836

Genus *Storchia* Oudemans, 1923

Storchia Oudemans, 1923b: 150; Wood, 1973: 88; Ueckermann and Meyer, 1987: 394; Meyer and Ueckermann, 1989: 51; Fan and Chen 1997: 161; Fan and Zhang 2005: 100; Seeman et al., 2023: 1517.

Apostigmaeus Grandjean, 1944: 105; Summers, 1964: 184; Summers, 1966: 243; Wood, 1967: 115; Meyer, 1969: 230; Vainstein and Kuznetsov, 1978: 166; Chaudhri et al., 1979: 204; Liang and Hu, 1988: 45.

***Diagnosis*:** Chelicerae distinct and separate. Palptibial claw comparable in length to palptarsus or minimally shorter; possess attenuated setiform accessory claw. Palptarsus features four setae, one solenidion ω, two preterminal spinelike eupathidia, and two discrete terminal eupathidia. Palp trochanter asetose, palp femur bears three setae, palp genu and tibia each usually equipped with two setae. Idiosoma elongate to broadly oval in outline. Prodorsal shield narrow and elongated, comprises setae *v1* and *v2*. Setae *sci* and *sce* positioned on platelets. Dorsal hysterosoma prominently striated and devoid of a demarcated shield. Hysterosomal setae *d1* and *d2* situated on individual platelets. Suranal shield medially divided, with two to three pairs of setae; setae *h3* inconsistently present. Ventral opisthosoma features four pairs of aggenital setae. Genital and anal plates distinct, bearing two to three pairs of genital setae and three pairs of pseudanal setae (*ps1*-*ps3*) respectively. Leg chaetotaxy including solenidiotaxy: Leg I: 2+1elcp, 1, 4, 4-5+1κ, 5+0-1ϕ+1ϕp, 13-14+1ω. Leg II: 2, 1, 4, 4 + 0-1κ, 5+1ϕp, 8-9+1ω. Leg III: 2, 1-2, 3, 2-3, 5+1ϕp, 6-7+1ω. Leg IV: 1-2, 1, 2-3, 2-3, 5+1ϕp, 6-8+1ω (coxal setae *1a*, *3a*, and *4a* omitted). Tarsal empodial shaft divides terminally, extending past the distal ends of tarsal claws, adorned with three pairs of tenent hairs. Stout and prominent tarsal claws present.

Type species: *Caligonus robustus* Berlese, 1885

Storchia pacifica (Summers, 1964)

PLATE 31 A, B

Apostigmaeus pacificus Summers, 1964: 184.

Storchia pacifica Fan and Chen, 1997: 163; Noei et al., 2007: 154; Seeman et al., 2023:1516.

Redescription

Female: Dorsum: Idiosoma oval, length of body (including gnathosoma) 577 (567– 646); width of body 283 (276–325). Dorsal setae barbed. Prodorsum exhibits a long prodorsal shield, reticulated, bearing two pairs of setae (*vi* and *ve*); eyes absent; setae *sci* and *sce* on ruffled integument; opisthosoma features six pairs of setae (*c1*, *d1*, *d2*, *e1*, *e2* and *f1*); suranal shield divided and possess two pairs of setae (*h1* and *h2*); setae *h3* situated ventrolateraly. Setae *c1* are positioned laterally. Length of dorsal setae *vi* 40 (39-44); *ve* 40 (39-44); *sci* 38 (37-42); *sce* 40 (39-44); *c1* 40 (39-44); *c2* 55 (54-61); *d1* 40 (39-44); *d2* 42 (41-47); *e1* 42 (41-47); *e2* 38 (37-42); *f1* 48 (47-53); *h1* 43 (42-48); *h2* 57(56-63). Striations transverse between setae *c1–c1* and *d1–d1*, longitudinal from setae *d1–d1* to *e1–e1*, and transverse again from *e1–e1* to the posterior margin.

Distances between dorsal setae: *vi–vi* 42 (41-47); *ve– ve* 60 (59-67); *vi–ve* 25 (24-28); *ve–sci* 74 (72-83); *vi–sce* 107 (105-119); *sci–sci* 147 (144-164); *sci–sce* 35 (34-39); *sce– sce* 174 (171-195); *c1–c1* 173 (167-193); *c1–d1* 93 (91-104); *d1–d1* 74 (72-83); *d2–d2* 224 (220-250); *d1–e1* 96 (94-107); *d1–e2* 91 (89-102); *d2–e2* 79 (77-88); *e1–e1* 77 (75-86); *e1–e2* 62 (60-69); *e1–f1* 44 (43-49); *e2–f1* 91 (89-102); *f1–f1* 94 (92-105); *f1–h1* 55 (54-61); *f1–h2* 56 (55-63); *h1–h1* 54 (53-60); *h1–h2* 42 (41-47); *h2–h2* 97 (95-108). Ratios (minimum–maximum): *vi*/(*vi–vi*) 0.8–0.9; *c1*/(*c1–c1*) 0.2–0.3; *d1*/(*d1–d1*) 0.4–0.5; *e1*/(*e1–e1*) 0.4–0.5; *f1*/(*f1–f1*) 0.4–0.5; *h1*/(*h1–h1*) 0.7–0.8; *h2*/(*h2–h2*) 0.5–0.6; *c1–c1*: *d1–d1*: *e1–e1*: *f1–f1* 2.3: 1: 1: 1.2.

Gnathosoma: length of gnathosoma 112 (106–118) width -110 (106-112). Cheliceral length is 93 (86-95), with the movable digit measuring 40 (36-42). Both rostral setae and subcapitular setae are simple. Two pairs of subcapitular setae present (*m* and *n*), *m* 38 (37-42), *n* 51 (50-57); adoral setae present, two pairs; *or1* 15 (14-17) and *or2* 15 (14–17); distances *m–m* 46 (45-51), *n–n* 41 (40-46); five segmented palpi; palp tarsus bears four setae, simple (*va*. *Ba*, *lp*, *bp*) and one ventral solenidion *ω* and two subterminal spiniform eupathidia and two terminal eupathidia (*sulξ*, *ul'ξ*, *ul''ξ*, *acmξ*). Palptibia bearing three setae, one seta-like accessory claw and one well-developed claw; palp genu equipped with two setae; palp femora feature three setae; palp trochanter acetose.

Venter: all ventral setae are smooth. Striations between coxae I–IV are longitudinal. Opisthoventer exhibits transverse striae extending posterior to coxae IV to setae *ag1*, with striations constituting a transverse arch between setae *ag1*. Length of setae *1a* 39 (38-43), *1b* 63 (61-70, *1c* 52 (51-58), *2b* 58 (37-65), *2c* 42 (41-47), *3a* 72 (70-80), *3b* 42 (41-47), *3c* 34 (33-38), *4a* 39 (38-43), *4b* 36 (35-40), *4c* 33 (32-37); aggenital area with four pairs of setae (*ag1– ag4*), *ag1* 31 (30-34), *ag2* 31 (30-34), *ag3* 39 (38-43) and a*g4* 37 (36-41); genital valves with two pairs of genital setae, *g1* 29 (28-32), *g2* 29 (28-32); pseudanal valves with three pairs of pseudanal setae (*ps1*–*ps3*), *ps1* 39 (32-43), *ps2* 36 (35-40), *ps3* 48 (47-53).

Legs: length of legs (from base of coxae to eupathedia): leg I 344 (338-385), leg II 278 (273-311), leg III 290 (284-324), leg IV 346 (340-387). Leg Chaetotaxy: coxae I-IV: 2–2–2–2, trochanters I-IV: 1–1–2–1, femora I-IV: 4–4–3–3, genua I-IV: 5 + 1*κ*– 4 + 1*κ* –3–3, tibiae I-IV: 5 + *φ* + *φρ*– 5 + *φρ* –5 + *φρ*–5 + *φρ*, tarsi I-IV: 13 + *ω*–8 + *ω*–6 + *ω*–6 + *ω*. Lengths of solenidia on tarsus: I 20 (18-23), II 16 (13-17), III 11 (9-13), IV 9 (7-12).

Material examined

- Twenty-seven female specimen from Kozhikode (Market Warehouse, 11° 14' 56.4" N, 75° 46' 38.0" E), collected from stored black gram on 04 December 2018 by Neeraj Martin.

Remarks

The present redescription of *Storchia pacifica* is based on a detailed examination of specimens collected from Kerala. This redescription was completed prior to the work of Seeman *et al*. (2023), although their publication published earlier. The findings are mostly in agreement with the observations made by Seeman. *et al*. (2023), but several notable differences have been identified. Precisely, the setae *ve*, *c1*, *d1*, *e2*, and *e1* are distally pointed rather than clavate, contrasting with the redescription provided by Seeman *et al*. (2023). Suranal seta *h2* does not exhibit significant elongation in the examined specimens, and all dorsal setae are nearly uniform in both shape and size. In addition, Seeman *et al*. (2023) reported an asymmetrical variation in Indian specimens, characterized by three genital setae on the left side and two on the right, such variation has not been observed in the specimens examined in this study. Seeman *et al*. (2023) did not provide detailed information regarding the Indian species. The Indian population of *S. pacifica* can be distinguished from other known populations by the morphology of its ventral setae, which are smooth, in contrast to the barbed setae observed in specimens from other countries as described by Seeman *et al*. (2023). Intraspecific variation is clearly evident. The present redescription outlines the unique morphological features of the Indian *S. pacifica*. A key to the world species of *Storchia* is provided.

Key to the world species of genus *Storchia*

1. All dorsal setae spinulate excluding *vi* and *ve*, tarsi I with 14 setae and one solenidion *ω* …………………………………………..…. *Storchia hakkariensis* Uluçay, 2014
- All dorsal setae smooth or plumose including *vi* and *ve*, tarsi I with less than 14 setae and one solenidion *ω* ……………………………….....……...…...…………...... 2
2. Number of dorsal setae 13 (*h3* absent), setae *ve* and *sci* equal in length…….……
……………………………………………….…...…… *S. pacifica* (Summers, 1964)
- Number of dorsal setae 14 (*h3* present), setae *ve* longer than *sci*……………………...3
3. Coxae IV with one setae…………………….…*S. shanghaiensis* (Liang and Hu, 1988)
- Coxae IV with two setae……………………..…………...………..………...…...4
4. Trochanter III with 2 setae ………………………….…………………..………...…...5
- Trochanter III with 1 setae ………………………….…………..………...…...6
5. Number of genital setae 3, genu I with 4 setae and one solenidion *κ*…………….
……………………………………………….........……*S. annae* Fan and Li, 1993
- Number of genital setae 2, genu I with 5 setae and one solenidion *κ*…………….
……………………………………………………..... *S. cuneata* Fan & Yan, 1997
6. Prodorsal shield smooth………………………………..…………..…………….…7
- Prodorsal shield reticulated……………………………………..…..........….......8
7. Tarsi I with 12 setae, number of genital setae 4, *ve*/*sci* ratio 2………………...…
………………….….…*S. ardabiliensis* Safasadati, Khanjani, Razmjou & Dogan, 2010
- Tarsi I with 13 setae, number of genital setae 4, *ve*/*sci* ratio 2.5……………..…....
……………………………………..…..……*S. hendersonae* Fan and Zhang, 2005
8. Setae *ve* 3 times longer than setae *sce*…………………..…………….………...……..9
- Setae *ve* less than 3 times longer than setae *sce*…………………..…………….……….10

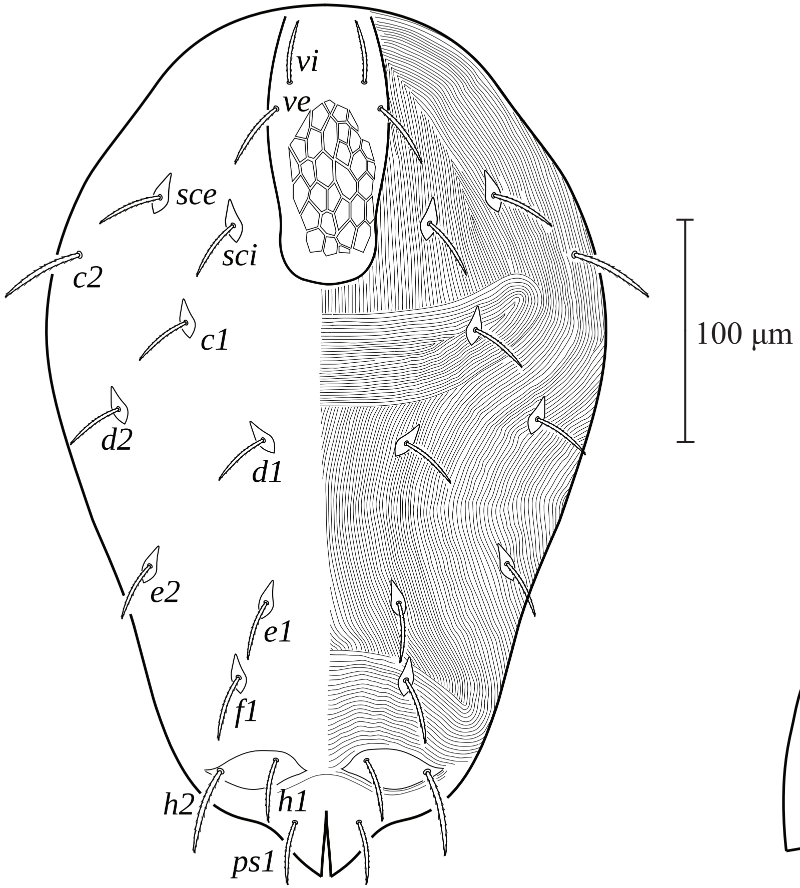
9. Setae *ve* 2.9 times longer than setae *sci*…………….….. *S. yazdaniani* Bagheri, Mohajer, Saboori, Asadeh & Ueckermann, 2011

- Setae *ve* 3.75 times longer than setae *sci*…………… *Storchia mehrvari* Bagheri & Gheblealivand, 2012

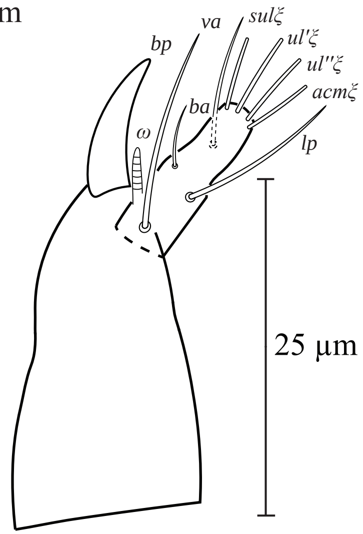
10. Tibiae I with 6 setae, *c1/ c1-c1* ratio 0.15……….…….……*S. elhamae* Hassanzadeh, Khanjani, Safaralizadeh & Mirfakhraie, 2013

- Tibiae I with 5 setae, *c1/ c1-c1* ratio 0.30……………..…..……*S. robustus* (Berlese, 1885)

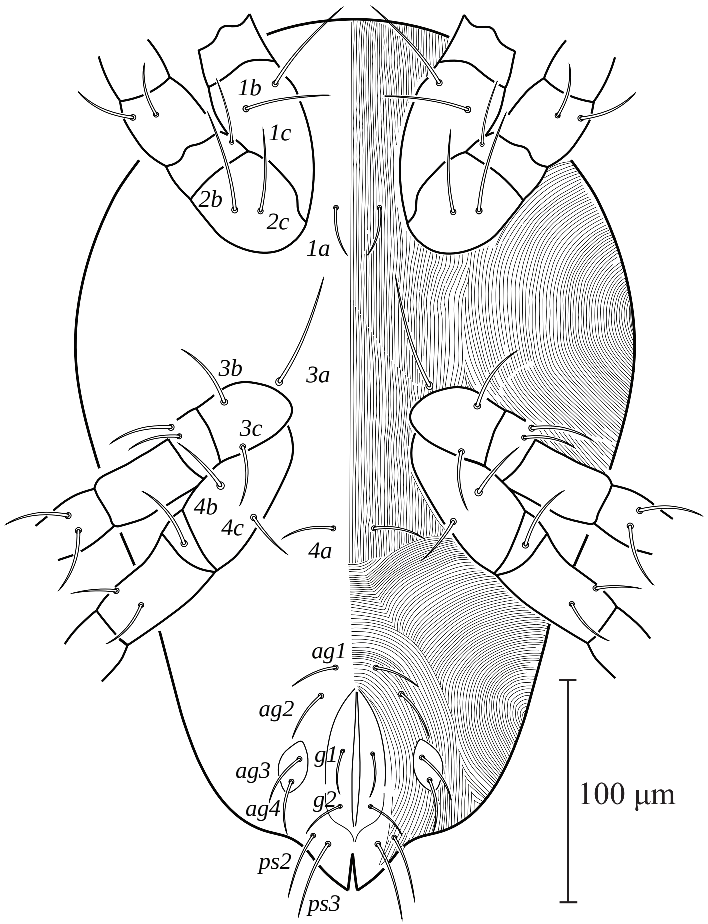
PLATE 31 A



Dorsum



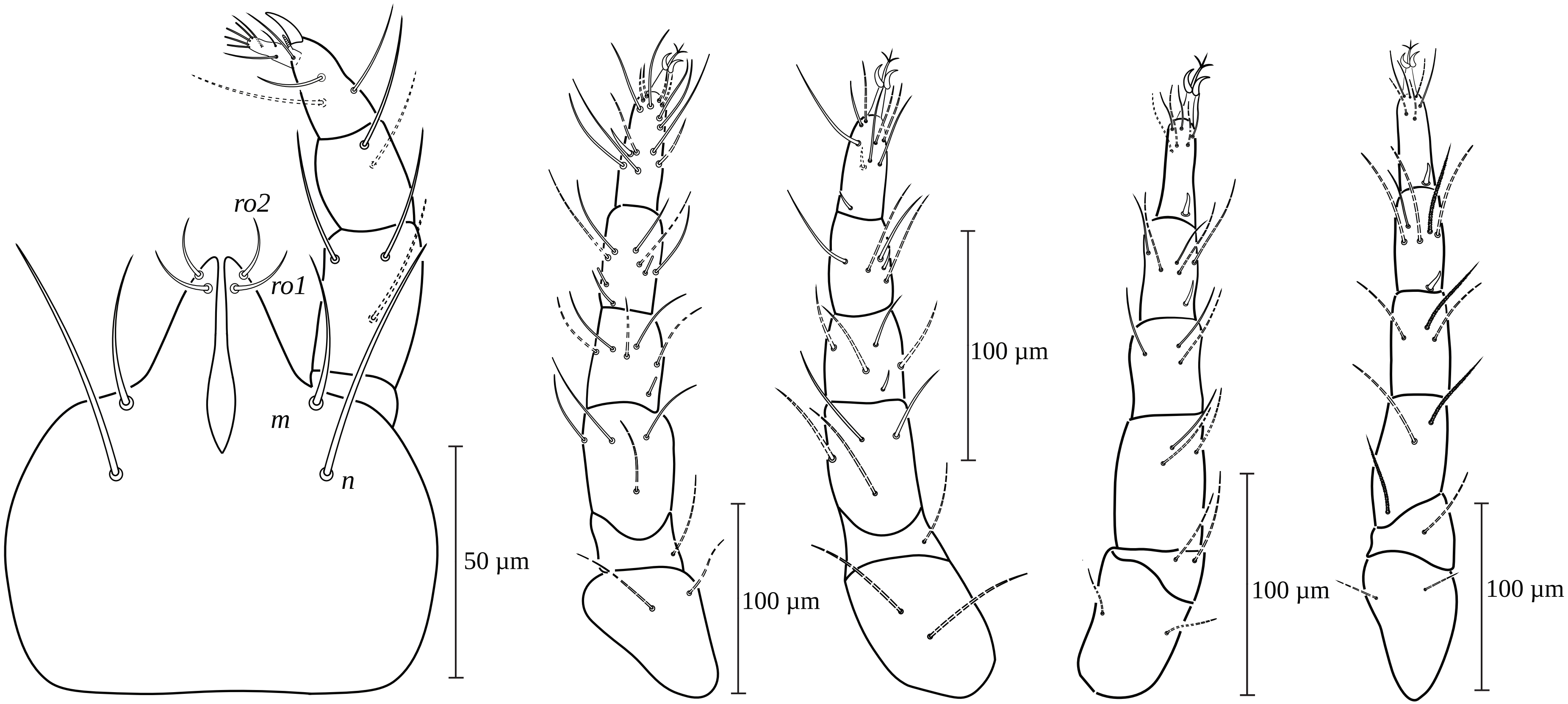
Palp tarsus



Ventrum

Storchia pacifica **(Summers, 1964), Adult female**

PLATE 31 B



Gnathosoma Leg I Leg II Leg III Leg IV

Storchia pacifica **(Summers, 1964), Adult female**

TABLE 4. List of predatory mite species reported for the first time from India

Si No	Species name	Family	Inhabited stored products
1	*Stratiolaelaps scimitus*	Laelapidae	Fox tail millet, chick pea, boiled rice, rice flakes
2	*Euandrolaelaps karawaiewi*	Laelapidae	Boiled rice
3	***Storchia pacifica***	Stigmaeidae	Black gram
4	***Acaropsella strioreticulata***	Cheyletidae	Wheat semolina
5	***Hoploseius andamensis***	Blattisocidae	Edible oyster mushroom
6	*Fessonia indica*	Smarididae	Raw rice
8	***Paraneognathus wangae***	Calligonellidae	Cowpea, cashew nut
9	*Raphignathus neocardinalis*	Raphignathidae	Dried chili
10	*Spinibdella ampulla*	Bdellidae	Raw rice
11	*Spinibdella tabarii*	Bdellidae	Raw rice
12	***Balaustium murorum***	Erythraeidae	Nutmeg
13	*Sejus carolinensis*	Sejidae	Walnut

******Bolded italics*** *entries indicate first records of the genus (and species) from India; italicized entries represent newly reported species only.*

PLATE 32

Figure 1-9. Microscopic slide images of predatory mites collected in the present study

1. *Androlaelaps casalis*

2. *Euandrolaelaps karawaiewi*

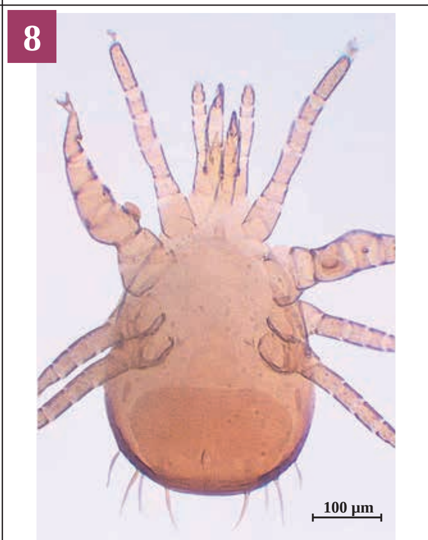
3. *Euandrolaelaps sardous*

4. *Stratiolaelaps scimitus*

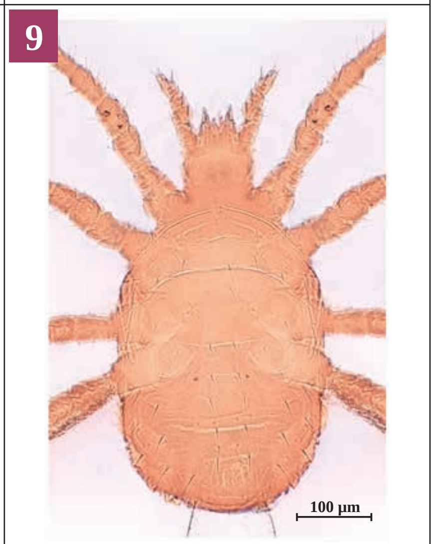
5. *Blattisocius dentriticus*

6. *Blattisocius keegani*

7. *Blattisocius tarsalis*



8. *Hoploseius andamanensis*



9. *Proctolaelaps bickleyi*

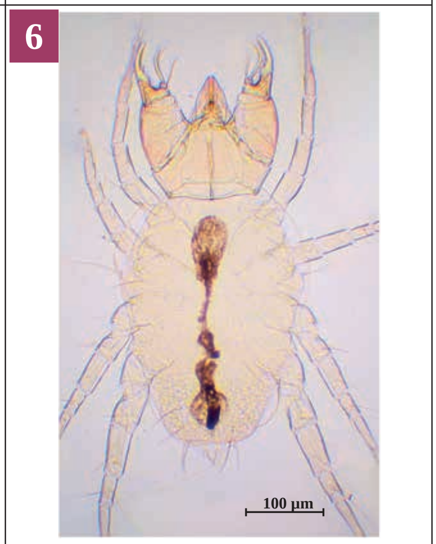
PLATE 33

Figure 1-9. Microscopic slide images of predatory mites collected in the present study

1. *Proctolaelaps pygmaeus*

2. *Amblyseius indirae*

3. *Sejus carolinensis*



4. *Acaropsella strioreticulata*

5. *Cheyletus carnifex*

6. *Cheyletus eruditus*

7. *Cheyletus malaccensis* (♀)

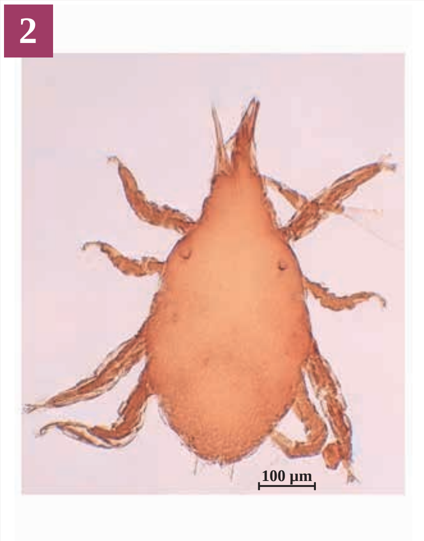
8. *Cheyletus malaccensis* (HM♂)

9. *Cheyletus malaccensis* (HetM♂)

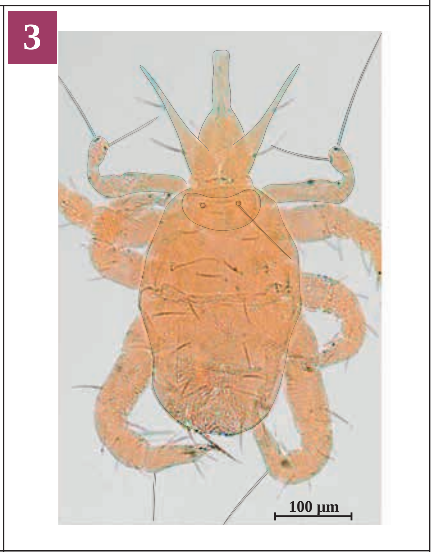
PLATE 34

Figure 1-9. Microscopic slide images of predatory mites collected in the present study

1. *Cheyletus trouessarti*



2. *Bdella distincta*

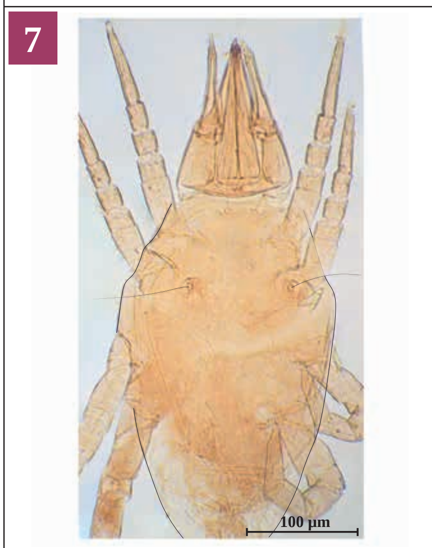


3. *Spinibdella ampulla*

4. *Spinibdella tabarii*

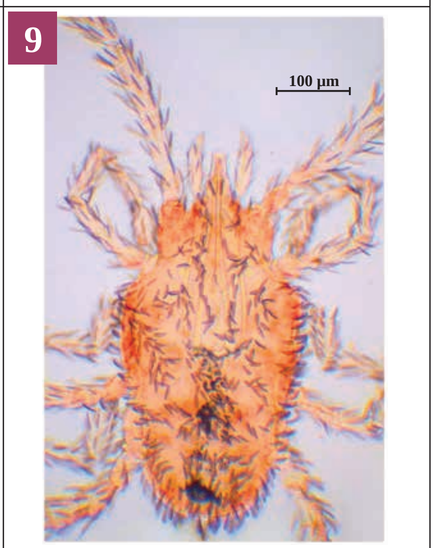
5. *Cunaxa capreolus*

6. *Cunaxa setirostris*



7. *Scutopalus pradhani*

8. *Balaustium murorum*



9. *Fessonia indica*

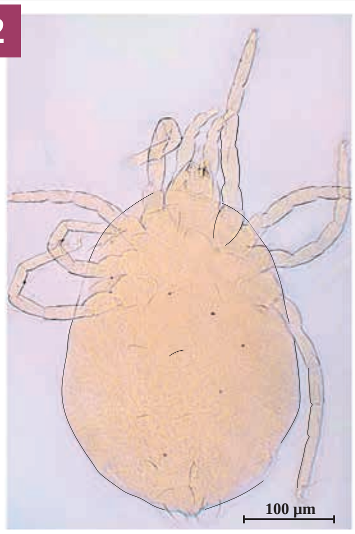
PLATE 35

Figure 1-3. Microscopic slide images of predatory mites collected in the present study

1

1. *Paraneognathus wangae*

2



2. *Raphignathus neocardinalis*

3

3. *Storchia pacificus*

4.3. Breeding Biology of *Cheyletus malaccensis* (Oudemans, 1903)

Breeding and developmental studies of the predatory mite *Cheyletus malaccensis* were conducted in the laboratory under three different temperatures, namely 25 ± 1 °C, 29 ± 1 °C, and 33 ± 1 °C, and at three relative humidity levels, viz. 70 ± 5%, 80 ± 5%, and 90 ± 5%. The predatory mites were reared on *Suidasia nesbitti* as prey. Various developmental stages and behavioural patterns were carefully observed and recorded hourly to ensure precise documentation under each of these environmental conditions.

The experimental temperature and humidity regimes (25 °C, 29 °C, and 33 °C; 70%, 80%, and 90% RH) were selected to simulate the ecological and physiological optimum for *Cheyletus malaccensis* and the microclimatic conditions typical of storage facilities in North Kerala. Published literature from multiple studies (e.g., Zhu et al., 2019; Elhalawany et al., 2022) indicates that the biological performance of this predatory mite declines significantly at temperatures below 20 °C and above 33 °C. Therefore, the chosen range enables the assessment of its maximum reproductive and predatory potential. Moreover, these parameters correspond to the warm, humid tropical environment of North Kerala warehouses, an environment that supports both *C. malaccensis* and its prey, *Suidasia nesbitti*. Executing trials within these ecologically relevant regimes ensures that observations of developmental stages and behavioural patterns are directly applicable to real-world pest management and biocontrol strategies in the region's stored-product ecosystems.

4.3.1. Mating behaviour

The experiment was initiated by placing a newly emerged adult diploid homomorphic male and female *Cheyletus malaccensis* in the rearing Petri dish. At first, they showed strong escape behavior, avoiding light by hiding in darker areas. After an acclimatization period of 1-2 hours, the mites stabilized and began actively preying on different developmental stages of *Suidasia nesbitti*, primarily targeting larvae and protonymphs.

Once settled, the male displayed distinct mate-searching behavior, moving rapidly across the substrate while intermittently pausing to assess chemical or tactile cues from the female. Upon locating a receptive female, the male approached cautiously, establishing initial contact using the first pair of legs. Male *C. malaccensis* positioned himself laterally alongside the female using his legs to gently clasp her idiosoma. The copulatory phase lasted approximately 20-35 minutes, during which the male rhythmically flexed his opisthosoma to ensure proper spermatophore placement. After successful transfer, the male gradually loosened his grip and dismounted often retreating quickly to resume foraging. The female, in contrast, remained stationary for a short period before resuming predatory activity.

4.3.2. Effects of temperature and humidity on pre-oviposition period

Under 25 °C temperature and different relative humidity combinations, it was shown that there was a statistically significant influence of humidity on the pre-oviposition period ($F(2,27) = 16.67$, $p < 0.001$). The pre-oviposition period was longest at 70% RH (3.10 ± 0.05 days), whereas it was 2.40 ± 0.17 days at 80% RH and shortest at 90% RH (2.00 ± 0.14 days). Tukey's HSD test indicated that 90% RH and 80% RH did not differ significantly ($p = 0.11$), but both were significantly different from 70% RH. This suggests an inverse tendency for humidity to shorten the pre-oviposition period, although the difference between 80% and 90% RH was not statistically significant (Table 5).

At 29°C, the role of relative humidity became very clear and exerted a significant effect on the pre-oviposition period ($F(2,27) = 58.41$, $p < 0.001$). The shortest pre-oviposition period occurred at 90% RH (2.10 ± 0.15 days), followed by 70% RH (2.53 ± 0.04 days), and the longest at 80% RH (2.76 ± 0.03 days). Post hoc tests revealed that all three RH levels were statistically distinct. The effect size (Partial $\eta^2 = 0.812$) confirmed a pronounced influence of humidity on reproductive timing at this temperature.

However, when the temperature shifted to 33°C, the statistical significance of the effect of humidity on the pre-oviposition period became weak, $F(2, 27) = 1.62$, $p = 0.21$, partial $\eta^2 = 0.10$. Post hoc tests showed that all humidity treatments fell within the same homogeneous subset (a), indicating non-significant differences. This may indicate that the temperature optimum lies at 29°C, where varying humidity levels have an influence, beyond which the effects of humidity on the pre-oviposition period become less pronounced.

TABLE 5. Effects of temperature and relative humidity on pre-oviposition

Temperature (°C)	Humidity (% RH)	Pre-oviposition days (Mean ± SE)
25	70	3.10 ± 0.05[a]
	80	2.40 ± 0.17[b]
	90	2.00 ± 0.14[b]
		CD = 0.52
29	70	2.53 ± 0.04[a]
	80	2.76 ± 0.03[b]
	90	2.10 ± 0.04[c]
		CD = 0.13
33	70	2.30 ± 0.16[a]
	80	1.90 ± 0.10[a]
	90	2.10 ± 0.19[a]
		CD = 0.55

n = 10. Means followed by the same letters do not differ significantly from each other by Tukey's HSD subset grouping. The corresponding CD value at the 0.05 significance level is reported for each temperature–humidity set.

4.3.3. Oviposition behavior and maternal care in *Cheyletus malaccensis*

Adult female *Cheyletus malaccensis* demonstrated clear substrate preferences during oviposition, showing a strong selection for the textured surfaces of wheat grain fragments over smoother wheat flakes. The irregular topography of grain substrates might appear to facilitate egg adhesion. Females deposited elliptical-shaped, pale white coloured eggs mainly on elevated surfaces. During microscopic examination, photophobic responses prompted females to retreat beneath grain substrates while leaving their egg clusters exposed.

The oviposition process occurred in distinct nesting phases, with individual females typically producing between three to four egg clusters throughout their reproductive cycle. Female *C. malaccensis* exhibited remarkable maternal care behaviors, including the transportation of eggs using their third pair of legs. Females were capable of carrying up to three eggs simultaneously, carefully cradling them on their ventral side while moving across the substrate. This egg-carrying behavior was accompanied by vigorous nest defence strategies, where females displayed protective postures to deter approaching males. In more extreme interactions, this defensive behavior escalated to sexual cannibalism, with females consuming their mates, which can be considered as a potentially adaptive response to reproductive stressors under laboratory conditions.

To ensure optimal population management and enhance egg survivability, a systematic approach was implemented where egg clutches were carefully collected daily and transferred to fresh rearing Petri dishes. This methodology served multiple important functions in the experimental setup. Primarily, it prevented overcrowding and subsequent resource competition among developing nymphs, while simultaneously allowing for clearer observation of individual eggs by eliminating the visual interference caused by prey mites, wheat fragments and overlapping egg masses in the original containers. The partitioning of egg clusters facilitated accurate developmental monitoring and population tracking throughout the study period.

4.3.4. Impact of thermal and humidity conditions on oviposition period

Varying humidity levels at 25 °C had a significant effect on the oviposition period, ($F_{(2,27)} = 80.11$, $p<0.001$, $\eta^2=0.85$), accounting for 85.6% of observed variance. The period decreased linearly with increasing humidity; longest at 70% RH and shortest at 90% RH, with all pairwise comparisons significant ($p\leq0.001$) (Plate 36, Figure A).

At 29°C, the effect remained highly significant ($F_{(2,27)} = 153.17$, $p<0.001$, $\eta^2=0.91$) but followed a non-linear pattern. While 90% RH yielded the shortest period and 70% RH was intermediate, 80% RH unexpectedly resulted in the longest duration (all $p<0.001$) (Plate 36, Figure B). This suggests 80% RH may mitigate thermal stress at warmer temperature levels, though elevated humidity (90%) could induce hygric stress.

The trend persisted at 33°C ($F_{(2,27)} = 104.56$, $p<0.001$, $\eta^2=0.886$), with 80% RH again showing the longest period (18.90 days) and 90% RH the shortest (11.00 days; all $p<0.001$) (Plate 36, Figure C). This reinforces that moderate humidity (80% RH) optimizes oviposition under thermal stress, whereas extreme humidity levels (70% or 90% RH) are suboptimal.

4.3.5. Role of varying temperature and humidity levels on post-oviposition period

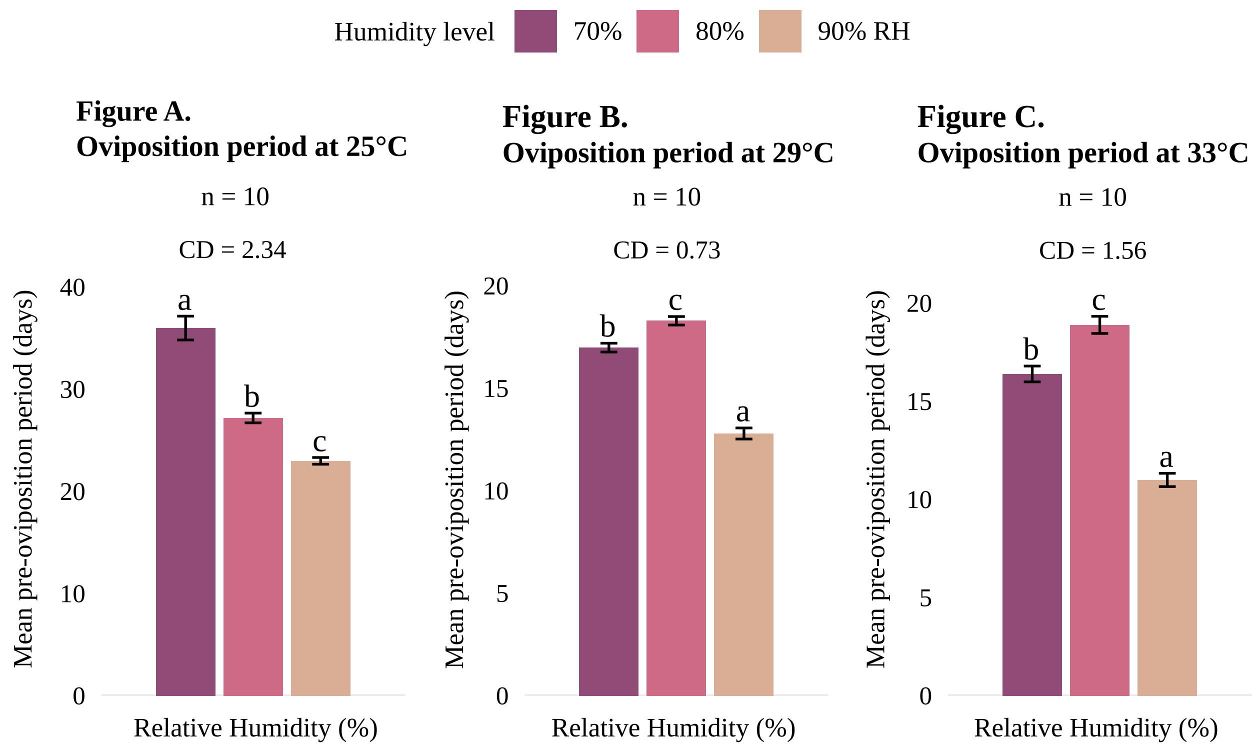
Under a constant temperature of 25 °C, relative humidity significantly influenced post-oviposition duration ($F_{(2,27)} = 5.87$, $p=0.008$, $\eta^2=0.30$), but only the 70% vs. 90% RH comparison was significant ($p=0.007$), with 80% RH positioned intermediately and statistically indistinguishable from 80% RH. The effect was stronger at 29°C ($F_{(2,27)} =33.18$, $p<0.001$, $\eta^2=0.71$), where all pairwise differences were significant ($p\leq0.003$). Post-oviposition duration dropped from 80% RH (3.40 days) to 90% RH (2.61 days). At 33°C ($F_{(2,27)} =23.41$, $p<0.001$, $\eta^2=0.63$), 80% RH (3.00 days) significantly exceeded both 70% and 90% RH ($p<0.001$), which did not differ from each other ($p=0.482$) (Table 6).

The relationship between humidity and oviposition/post-oviposition periods varied distinctly with temperature. At 25°C, higher humidity linearly shortened both phases, with 70% RH yielding the longest durations and 90% RH the shortest. However, this pattern changed at warmer temperatures (29-33°C), where 80% RH consistently prolonged durations compared to extreme humidity levels (70% or 90% RH). This suggests that moderate humidity (80% RH) may stabilize physiological processes under higher temperature levels, despite extending post-oviposition periods.

The lowest humidity level (70% RH) had a stronger and lengthening effect on the post-oviposition period at cooler temperatures (25 °C), but exerted a weaker influence under warmer conditions. The stabilizing role of 80% RH emerged clearly at elevated temperatures (29-33°C), where it optimized oviposition while slightly delaying post-oviposition.

PLATE 36

Figure A–C. Effects of different temperature & humidity on oviposition period (mean ± SE)



[Grouping letters (a, b, c) are based on critical difference (CD) values from Tukey's HSD test ($p < 0.05$)]

TABLE 6. Effects of temperature and relative humidity on post-oviposition period.

Temperature (°C)	Humidity (% RH)	Post-oviposition days (Mean ± SE)
25	70	3.50 ± 0.106 [a]
	80	3.00 ± 0.141 [b]
	90	2.80 ± 0.187 [b]
		CD = 0.66
29	70	2.61 ± 0.055 [a]
	80	3.40 ± 0.063 [b]
	90	3.08 ± 0.085 [c]
		CD = 0.30
33	70	1.90 ± 0.100 [a]
	80	3.00 ± 0.165 [b]
	90	2.10 ± 0.083 [a]
		CD = 0.58

n = 10. Means followed by the same letters do not differ significantly from each other by Tukey's HSD subset grouping. The corresponding CD value at the 0.05 significance level is reported for each temperature–humidity set.

4.3.6. Role of temperature and humidity on fecundity

At a constant temperature of 25°C, humidity levels significantly influenced fecundity, as evidenced by statistical analysis ($F_{(2,27)} = 231.24$, $p < 0.001$). A strong fit was observed, with the model explaining over 90% of the variation in egg production (adjusted $R^2 = 0.941$). The highest number of eggs was observed at 70% relative humidity (RH) (292.6±2.74 eggs), followed by 80% RH (227.40±4.72 eggs), and the lowest at 90% RH (172.0±4.16 eggs). Tukey's HSD test confirmed significant differences among all pairwise comparisons ($p < .001$), with each humidity level forming a distinct group. The results demonstrated that increasing humidity at a constant temperature (25°C) leads to a substantial reduction in reproductive output (Table 7).

At 29°C ($F_{(2,27)} = 39.13$, $p < 0.001$), peak fecundity was recorded at 80% RH (139.9±2.83 eggs), followed by 70% RH (127.0±2.63 eggs), with the lowest observed at 90% RH (105.0±2.99 eggs) (Table 7). Post hoc tests confirmed significant differences across all three humidity levels ($p < 0.01$), suggesting that excessively high humidity adversely affected reproductive output. The substantial effect size (Partial $\eta 2 = 0.743$) further confirms the strong influence of humidity on oviposition at this temperature.

Fecundity continued to differ significantly among the three relative humidity levels at 33°C ($F_{(2,27)} = 16.13$, $p < 0.001$). The highest egg production occurred at 80% RH (120.0±3.48 eggs), followed by 70% RH (108.0±4.19 eggs), and the lowest at 90% RH (90.0±3.56 eggs). Post hoc tests revealed significant differences between 90% RH and both 70% RH ($p = 0.006$) and 80% RH ($p < 0.001$). However, the difference between 70% and 80% RH was not statistically significant ($p = 0.080$). A moderate effect size (Partial $\eta 2 = 0.544$) indicated a notable influence of relative humidity on reproductive output at this temperature.

Overall, 25°C with 70% RH showed most favourable for fecundity, yielding the highest egg count. At higher temperatures like 29°C and 33°C, 80% RH became optimal, indicating a shift in humidity preference with increasing temperature. Across all temperatures, however, 90% RH consistently hindered reproductive success, indicating a clear upper limit to humidity tolerance. At 25°C, the relatively cooler temperature combined with moderate humidity (70% RH) likely created a balanced environment for fecundity. However, at 29°C and 33°C, 70% RH may have contributed to excessive dryness under warmer conditions, making it less favorable. In these cases, 80% RH may have mitigated the heat stress more effectively.

TABLE 7. Role of temperature and relative humidity on fecundity.

Temperature (°C)	Humidity (% RH)	Fecundity (Mean ± SE)
25	70	292.60 ± 2.74 [a]
	80	227.40 ± 4.72 [b]
	90	172.00 ± 4.16 [c]
		CD = 13.91
29	70	127.00 ± 2.63 [a]
	80	139.90 ± 2.83 [b]
	90	105.00 ± 2.99 [c]
		CD = 9.90
33	70	108.00 ± 4.19 [a]
	80	120.00 ± 3.48 [a]
	90	90.00 ± 3.56 [b]
		CD = 12.02

n = 10. Means followed by the same letters do not differ significantly from each other by Tukey's HSD subset grouping. The corresponding CD value at the 0.05 significance level is reported for each temperature–humidity set.

4.3.7. Effects of temperature and humidity on egg incubation period

Egg incubation duration showed a clear and temperature-dependent sensitivity to relative humidity (RH). At 25°C, incubation was significantly prolonged at 80% RH (3.90 days) compared to both 70% (3.00 days) and 90% RH (2.80 days), with the latter two showing no statistical difference. The effect of humidity was highly significant ($F_{(2,27)} = 14.13$, $p < 0.001$)

At a moderate temperature (29°C), a reversed trend was observed, in which incubation lasted longest at 70% RH (2.30 days) and was significantly shorter at both 80% (2.125 days) and 90% RH (2.15 days), which again did not differ from each other. The humidity effect remained statistically significant ($F_{(2,27)} = 5.36$, $p = 0.011$), In contrast, at the highest temperature tested (33°C), humidity had no significant effect on incubation period ($F_{(2,27)} = 1.01$, $p = 0.378$), with durations ranging from 1.90 to 2.20 days across RH levels (Table 8).

The relationship between humidity and incubation duration is both temperature-dependent and non-linear. Moderate humidity (80%) prolonged the incubation period at 25°C, likely preventing desiccation and supporting proper embryonic development. At higher temperatures (particularly 33°C), the incubation period became less sensitive to humidity, suggesting that temperature had a stronger influence than humidity on egg incubation duration.

TABLE 8. Effects of temperature and relative humidity on egg incubation period.

Temperature (°C)	Humidity (% RH)	Egg incubation period in days (Mean ± SE)
25	70	3.00 ± 0.09[a]
	80	3.90 ± 0.24[b]
	90	2.80 ± 0.10[a]
		CD = 0.69
29	70	2.30 ± 0.03[a]
	80	2.12 ± 0.03[b]
	90	2.15 ± 0.05[b]
		CD = 0.11
33	70	1.90 ± 0.14[a]
	80	2.20 ± 0.20[a]
	90	2.00 ± 0.09[a]
		CD = 0.72

n = 10. Means followed by the same letters do not differ significantly from each other by Tukey’s HSD subset grouping. The corresponding CD value at the 0.05 significance level is reported for each temperature–humidity set.

4.3.8. Developmental traits and environmental responses of larval, protonymphal, and deutonymphal stages at different temperatures and humidity levels

The post-embryonic development of *C. malaccensis* commenced with the emergence of larvae from the incubated eggs. The newly hatched larvae were inactive, slow-moving, and remained near unhatched eggs. Their bodies appeared lightly sclerotized and they possessed only three pairs of legs. After a few hours, the larvae displayed feeding behavior by consuming prey eggs. A non-feeding, quiescent stage occurred at the end of the larval phase; however, this stage was excluded from statistical analysis.

Subsequently, the larva of *C. malaccensis* underwent its first moult, marking the onset of the protonymph stage. The moulting process was characterized by a consistent pattern of rupture. Examination of the cast skins revealed they were split transversely at or near the scapular groove. This rupture was sometimes complete, leading to the two parts of the old skin being distinctly separated. This process appeared uniform across all developmental stages. In some instances, the posterior section of the cast skin also exhibited a lateral rupture, extending backward from the primary transverse one. The protonymph was found to be larger than the larva and possessed four legs. Following the moult, a brief inactive period was noted, after which feeding was initiated, primarily preying on the larval stages of *Suidasia nesbitti*. At the end of the protonymphal stage, a short quiescent phase was observed, similar to that seen in the larval stage.

Upon completion of this quiescent period, only the female protonymph moulted to enter the deutonymphal stage. The deutonymphal stage occurred exclusively in females. This was an actively feeding phase during which deutonymphs preyed on various developmental stages of *Suidasia nesbitti*. After a short quiescent period, the deutonymph underwent its final moult and emerged as an adult. The transition to this stage marked a notable increase in mobility and feeding activity. The deutonymphs were observed to consume prey more frequently compared to earlier stages.

At 25°C, larval development was markedly prolonged at 80% RH (6.80 ± 0.21 days) compared to both 70% RH and 90% RH ($p < 0.001$; $F_{(2,27)} = 105.7$, $p < 0.001$, $\eta^2 = 0.89$), indicating a pronounced humidity effect. A similar but slightly less intense pattern emerged at 29°C, where all pairwise differences were significant ($F_{(2,27)} = 46.89$, $p < 0.001$, $\eta^2 = 0.776$), following the trend: 80% > 70% > 90% RH. At 33°C, although humidity still had a significant effect ($F_{(2,27)} = 3.76$, $p = 0.036$, $\eta^2 = 0.218$), the differences were less pronounced, with only 70% RH resulting in a significantly longer larval duration than 90% RH ($p = 0.042$), and 80% RH being statistically intermediate (Table 9).

A consistent pattern emerged in the protonymphal stage, especially at 25°C and 29°C, where 80% RH resulted in significantly prolonged development compared to both 70% and 90% RH. At 25°C, durations followed: 80% RH (6.15 ± 0.20) > 70% RH (4.76 ± 0.11) > 90% RH (3.45 ± 0.10) with all comparisons significant ($p < 0.001$; $F_{(2,27)} = 80.77$, $\eta^2 = 0.857$). An even stronger effect was seen at 29°C ($F_{(2,27)} = 291.56$, $p < 0.001$, $\eta^2 = 0.956$), where 80% RH significantly prolonged development over both lower and higher humidities, with tight error margins. However, at 33°C, humidity had no significant influence on protonymphal duration (F (2,27) = 0.493, $p = 0.616$, $\eta^2 = 0.035$), indicating a diminished sensitivity to RH under higher thermal stress (Table 9).

In deutonymphs, 80% RH again led to the longest durations at both 25°C (5.70 ± 0.20 days) and 29°C (3.70 ± 0.047 days) with statistically significant differences from 70% and 90% RH ($p < 0.001$ for most; F = 62.22 and 27.00, respectively). At 25°C, all pairwise differences were significant ($\eta^2 = 0.822$), while at 29°C, the difference between 70% and 90% RH was not significant. At 33°C, RH did not significantly affect deutonymphal duration (F (2,27) = 2.578, $p = 0.094$, $\eta^2 = 0.160$), though a marginal trend toward longer development at 80% RH was observed (vs 90%, $p = 0.078$) (Table 9).

Across all three stages and temperatures, a consistent trend emerged in which 80% RH prolonged development significantly at lower temperatures (25°C and 29°C), while the effect of humidity diminished or disappeared at 33°C. This suggests a non-linear interaction between temperature and humidity, where moderate RH (80%) may create slightly unfavourable conditions. At 33°C and 70% RH, desiccation may induce developmental acceleration.

At higher temperatures (33°C), temperature becomes the dominant developmental driver, potentially overriding humidity effects. The decreased effect sizes (η^2 as low as 0.035) and non-significant pairwise differences suggest that larvae and nymphs may exhibit thermal stress-induced developmental acceleration, where developmental timing becomes compressed across RH conditions. Humidity, particularly at 80%, significantly slows immature stage development at 25°C and 29°C, but this influence wanes at higher temperatures. This indicates that moderate humidity under cooler thermal conditions may disrupt optimal physiological water balance, leading to delayed development. At high temperatures, developmental speed increases regardless of humidity, likely due to increased metabolic rates and potential stress-induced compensatory mechanisms (Hallas, 1981).

TABLE 9. Effects of temperature and humidity on larval and nymphal stages.

Temperature (°C)	Humidity (% RH)	Larval duration in days (Mean ± SE)	Protonymph duration in days (Mean ± SE)	Deutonymph* duration in days (Mean ± SE)
25	70	4.40 ± 0.11[a]	4.76 ± 0.11[b]	4.90 ± 0.08[b]
	80	6.80 ± 0.21[b]	6.15 ± 0.20[c]	5.70 ± 0.20[c]
	90	4.00 ± 0.068[a]	3.45 ± 0.10[a]	3.30 ± 0.15[a]
		CD = 0.58	CD = 0.67	CD = 0.69
29	70	3.300 ± 0.06[b]	2.61 ± 0.02[b]	3.20 ± 0.07[a]
	80	3.850 ± 0.05[c]	3.42 ± 0.03[c]	3.70 ± 0.04[b]
	90	3.000 ± 0.07[a]	2.25 ± 0.04[a]	3.00 ± 0.07[a]
		CD = 0.25	CD = 0.16	CD = 0.24
33	70	3.500 ± 0.20[a]	2.53 ± 0.11[a]	3.08 ± 0.13[a]
	80	3.400 ± 0.16[ab]	2.65 ± 0.09[a]	3.30 ± 0.22[a]
	90	2.900 ± 0.11[b]	2.50 ± 0.12[a]	2.80 ± 0.08[a]
		CD = 0.68	CD = 0.56	CD = 0.55

n = 10. Means followed by the same letters do not differ significantly from each other by Tukey's HSD subset grouping. The corresponding CD value at the 0.05 significance level is reported for each temperature–humidity set. *Deutonymph stage is only present in females.

4.3.9. Influence of varying temperature and humidity on development time

Developmental time of *Cheyletus malaccensis* from egg to adult stage was markedly influenced by humidity in both males and females, with statistical significance across multiple temperatures conditions. At 25°C, females exhibited a strong humidity effect (F (2.27) =128.101, p<0.001, η^2=0.905), with development times longest at 80% RH (22.60 ± 0.59 days), followed by 70% RH (17.12 ± 0.33 days), and shortest at 90% RH (13.60 ± 0.16 days), all pairwise differences being significant (p<0.001). Similarly, males showed highly significant differences (F (2.27) =134.922, p<0.001, η^2=0.909), with the same humidity-dependent trend (80% RH: 16.80 ± 0.39 days; 70% RH: 12.10 ± 0.27 days; 90% RH: 10.20 ± 0.16 days) (Plate 37, Figure A).

When temperature elevated to 29°C, the humidity effect remained highly significant for both females (F (2.27) =69.605, p<0.001, η^2=0.838) and males (F (2.27) =89.807, p<0.001, η^2=0.869), with development times following the same order: 80% RH > 70% RH > 90% RH

(Plate 37, Figure B). However, at 33°C, the effect weakened substantially. For females, only the 80% vs. 90% RH comparison was significant ($p=0.008$), with a moderate effect size ($\eta^2=0.284$). Males showed no significant humidity effect at 33°C ($F_{(2.27)}=2.404$, $p=0.109$, $\eta^2=0.151$) (Plate 37, Figure C).

These results indicated that humidity significantly influences development duration at lower temperatures (25°C and 29°C), with higher humidity (90% RH) accelerating development, while its effect diminishes or disappears at 33°C. The strong effect sizes and highly significant p-values at 25°C and 29°C confirm humidity as a critical factor, whereas temperature appears to override humidity effects at 33°C.

4.3.10. Adult longevity and lifespan

a) Adult female longevity

Female longevity was longest at 25°C and 70% RH (42.60 days), which was decreased through 80% (32.60) and lowest at 90% (27.80) at the same temperature, with large effect size ($\eta^2 = 0.873$) and all differences were statistically significant ($p \leq 0.001$) (Plate 38, Figure A). The pattern peaked at 29°C ($F_{(2,27)} = 152.110$, $p < 0.001$, $\eta^2 = 0.918$), where 80% RH (24.46 days) yielded the highest longevity, although only slightly better than 70% RH (22.60), both noticeably higher than 90% RH (17.51) (Plate 38, Figure B). At 33°C, female longevity again stood prolonged at 80% RH (23.80 days), then 70% (21.00), with the lowest at 90% RH (15.20) (Plate 38, Figure C). The effect remained highly significant ($F_{(2,27)} = 66.874$, $p < 0.001$, $\eta^2 = 0.832$), indicating that while increasing temperature reduces overall longevity, the higher humidity levels especially 90% remains consistently detrimental.

b) Adult male longevity

Male longevity was consistent with similar trend. At 25°C, longevity declined sharply from 70% RH (35.70 days) to 90% (21.30), with 80% RH (26.80) as intermediate. This effect ($F_{(2,27)} = 113.746$, $p < 0.001$, $\eta^2 = 0.894$) and pairwise differences ($p < 0.001$) were strong and clearly significant (Plate 38, Figure A). At 29°C, longevity was highest at 80% RH (19.41), which was significantly higher than 70% RH (16.26), with 90% RH again lowest (13.40). All differences were statistically meaningful ($F_{(2,27)} = 203.792$, $p < 0.001$, $\eta^2 = 0.938$). At 33°C, the same ranking persisted, but the difference between 70% and 80% RH was not significant ($p = 0.329$), though both exceeded 90% RH (13.10 days), showing that at high temperatures, 70–80% relative humidity conditions become functionally similar in terms of longevity.

PLATE 37

Figure A–C. Effects of temperature & humidity on development time (egg to adult) (mean ± SE)

Figure A. Development time at 25°C

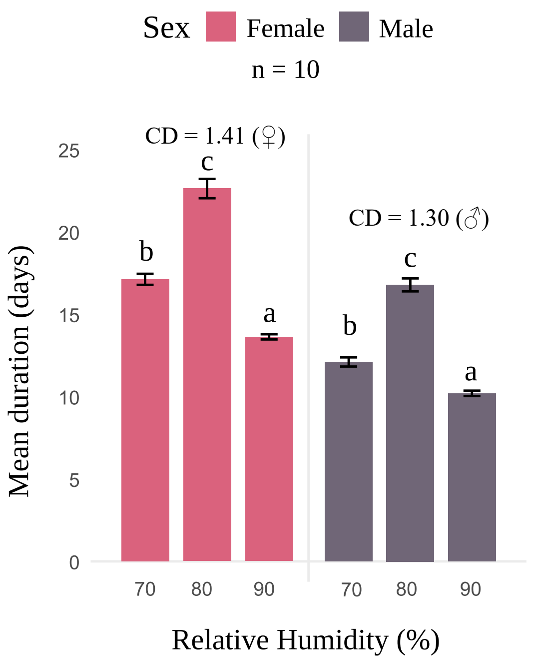


Figure B. Development time at 29°C

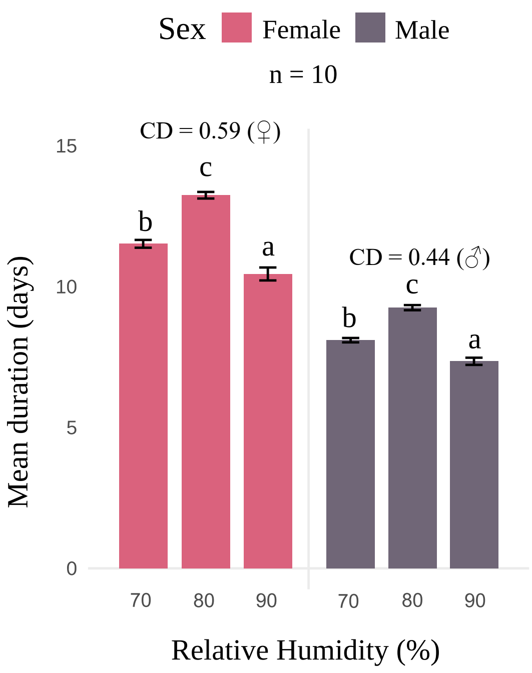
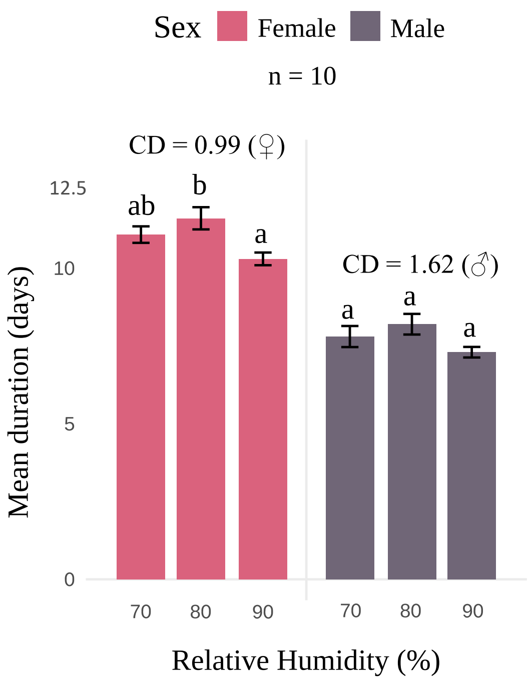


Figure C. Development time at 33°C



[Grouping letters (a, b, c) are based on critical difference (CD) values from Tukey's HSD test ($p < 0.05$)]

c) Female lifespan

Regarding female lifespan, the highest values consistently occurred at 70% RH across all temperatures. At 25°C, the effect of relative humidity was extremely strong ($F(2,27) = 98.765$, $p < 0.001$, $\eta^2 = 0.880$), with clearly distinct groups: 70% RH (59.72 days) > 80% RH (55.20 days) > 90% RH (41.40 days) (Plate 39, Figure A). All pairwise differences were statistically significant ($p \leq 0.007$), indicating meaningful biological separation. This pattern was even more pronounced at 29°C ($F(2,27) = 382.976$, $p < 0.001$, $\eta^2 = 0.966$), where the drop at 90% RH (27.96 days) compared to 80% RH (37.71 days) was substantial ($p < 0.001$) (Plate 39, Figure B). At 33°C, although overall lifespan declined, the humidity effect persisted ($F(2,27) = 50.412$, $p < 0.001$, $\eta^2 = 0.789$), with 80% RH (35.40 days) again superior to 70% (32.08) and 90% RH (25.50), and all differences remaining statistically significant ($p \leq 0.007$) (Plate 39, Figure C). The consistent pattern of better survival at moderate humidity suggests a physiological optimum near 70–80% RH, while 90% RH likely imposes stress, reducing the lifespan.

d) Male lifespan

For males, the pattern was almost similar but with sharper contrasts in some cases. Lifespan at 25°C followed a clear descending order with increasing humidity levels: 70% RH (47.80 days) > 80% (43.60) > 90% (31.50), with a very large effect ($F(2,27) = 116.230$, $p < 0.001$, $\eta^2 = 0.896$), and all differences significant ($p \leq 0.002$) (Plate 39, Figure A). At 29°C, male lifespan remained highest at 80% RH (28.66 days), followed by 70% (24.26), with the lowest again at 90% RH (20.75). The effect size was exceptionally large ($\eta^2 = 0.948$) (Plate 39, Figure B). At 33°C the difference between 70% and 80% RH became statistically non-significant ($p = 0.237$), though both still outperformed 90% RH (20.40 days) (Plate 39, Figure C). Here, the effect was still strong ($\eta^2 = 0.704$), but it suggests that at this elevated temperature, the range of humidity *C. malaccensis* can tolerate became narrower.

In summary, both longevity and lifespan of *C. malaccensis* were highly sensitive to relative humidity, with moderate levels (70–80% RH) consistently supporting better survival. The negative impact of 90% RH was evident across all conditions, possibly due to physiological stress associated with excessive moisture. Temperature controlled this relationship, with higher temperatures reduced the longevity and lifespan but maintained the general humidity trend.

PLATE 38

Figure A–C. Effects of temperature & humidity on adult longevity (mean ± SE)

Figure A. Longevity at 25°C

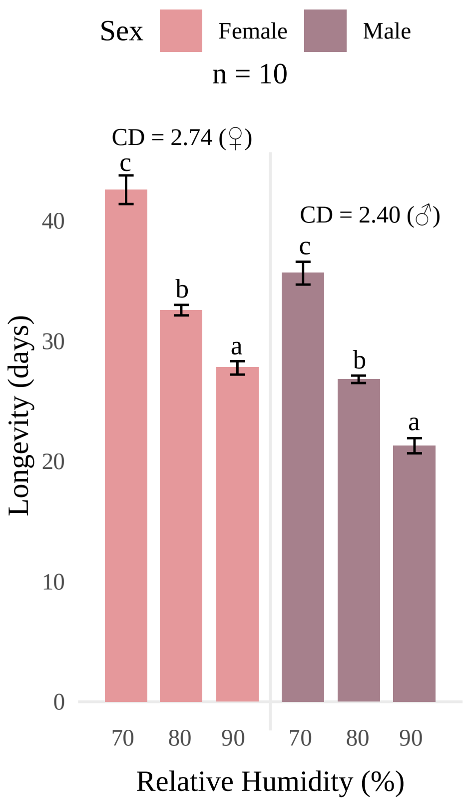


Figure B. Longevity at 29°C

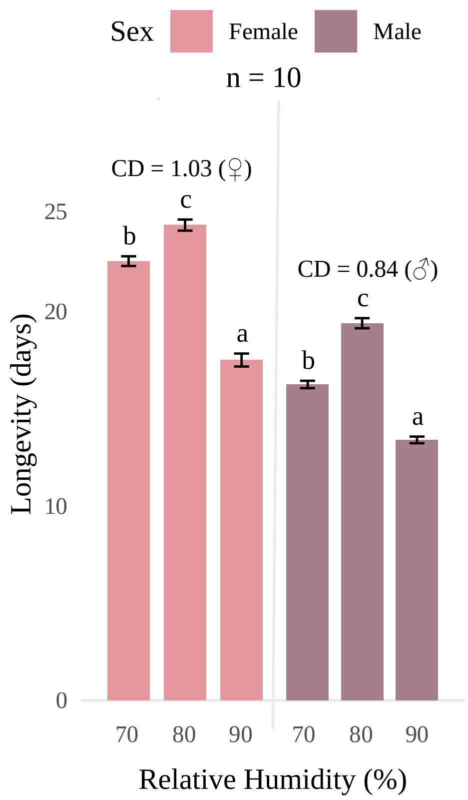
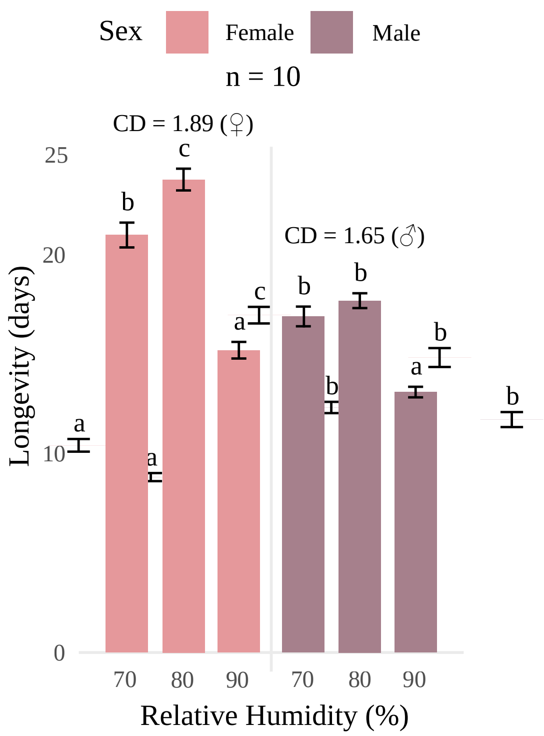


Figure C. Longevity at 33°C



[Grouping letters (a, b, c) are based on critical difference (CD) values from Tukey's HSD test ($p < 0.05$)]

PLATE 39

Figure A–C. Effects of temperature & humidity on lifespan (mean ± SE)

Figure A. Lifespan at 25°C

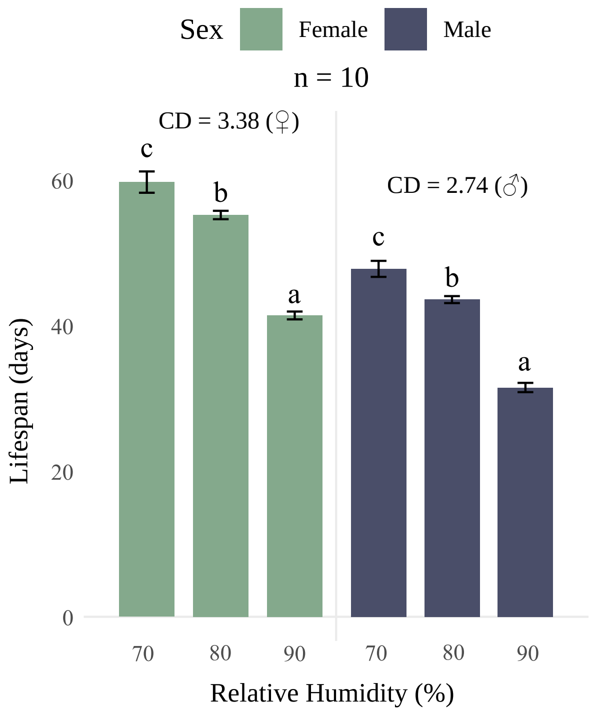


Figure B. Lifespan at 29°C

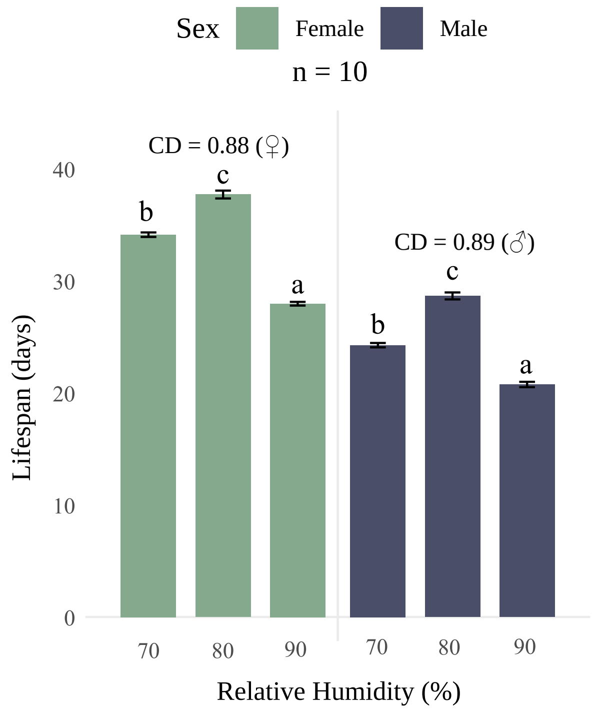
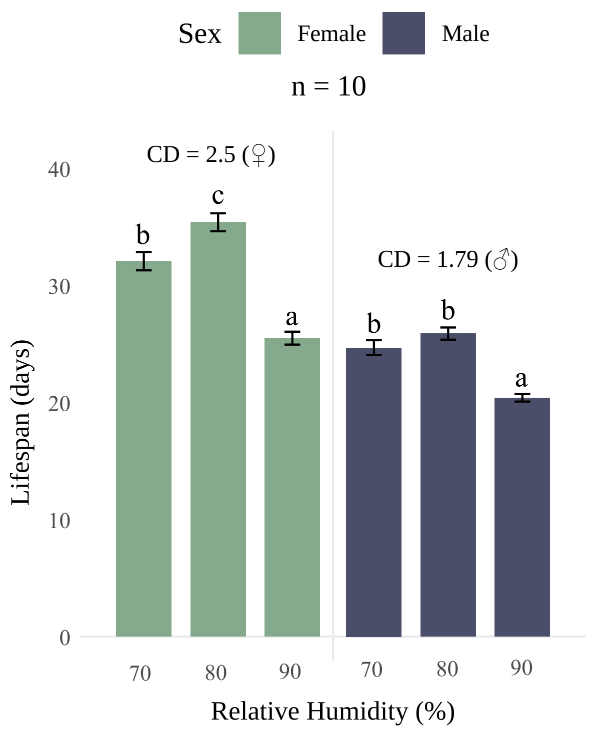


Figure C. Lifespan at 33°C



[Grouping letters (a, b, c) are based on critical difference (CD) values from Tukey's HSD test ($p < 0.05$)]

4.3.11. Influence of temperature and humidity on overall population dynamics

Temperature and relative humidity significantly influenced all measured life history traits of *Cheyletus malaccensis*, including fecundity, survival, development, and population growth metrics. These effects varied in magnitude and direction depending on the specific temperature-humidity combination, highlighting a complex interplay without a universally optimal condition.

At 25°C, although fecundity peaked at 70% RH (292.60 ± 2.75 eggs) and reproductive rate (R_0 = 108.10 ± 1.84) was highest, the longer development time (17.12 ± 0.33 days) and moderate survival (70.0 ± 0.57%) compromised efficiency (Table 10). Increasing RH to 80% and 90% at this temperature reduced fecundity and extended generation time. Notably, at 25°C/80% RH, development was slowest (22.60 ± 0.59 days), and reproductive rate decreased substantially (R_0 = 86.60 ± 3.49), suggesting that elevated humidity at cooler temperatures impairs reproductive efficiency.

In contrast, 29°C showed overall favorable and balanced performance, especially under 80% RH, which emerged as a robust thermal-humidity combination. Although fecundity (139.90 ± 2.83) was lower than at 25°C, the shorter development time (13.25 ± 0.12 days), higher survival rate (78.2 ± 0.27%), and moderate intrinsic growth rate (rm = 0.251 ± 0.002) suggest a trade-off that supports more efficient population turnover. 29°C/90% RH recorded the highest intrinsic rate of increase (rm = 0.292 ± 0.005) and the shortest doubling time (2.38 ± 0.04 days), but survival dropped slightly (70.4 ± 1.16%), and fecundity declined further (105.00 ± 2.99), indicating a narrowing of optimal humidity tolerance.

At 33°C, clear signs of thermal stress were observed across parameters. Fecundity dropped further, survival rates deteriorated (lowest at 90% RH: 40.1 ± 3.29%), and net reproductive rates declined sharply (R_0 = 23.60 ± 2.27 at 90% RH). Although development time accelerated (fastest at 10.30 ± 0.20 days), this was accompanied by reduced overall fitness. Notably, the influence of humidity at this temperature diminished or vanished in some traits such as pre-oviposition period, egg incubation period, nymphal duration and development time, suggesting that temperature, rather than humidity, became the primary limiting factor under thermal stress.

The results indicated that humidity effects were more distinct at 25°C, influencing fecundity and development duration. Nevertheless, at 33°C, these effects were overridden by temperature stress. No marked improvement was seen from 29°C to 33°C in most parameters, suggesting that an optimal thermal threshold may exist around or within 29°C, beyond which physiological stress impairs performance.

While 25°C/70% RH showed high reproductive potential, its longer development time and moderate survival limit ecological efficiency. In contrast, 29°C/80% RH represents a more ecologically favorable compromise, balancing faster development, higher survival, and acceptable reproduction. This trade-off may help the population persist better in changing field conditions, where faster development and higher survival can be more beneficial than producing the highest number of eggs.

Considering all results, temperature and humidity exert complex, trait-specific effects on *C. malaccensis*. There is no single optimal environment for maximizing all parameters simultaneously. Instead, different combinations favour different life history traits, and 29°C/80% RH emerges as a strong candidate for balanced population performance in terms of speed, survival, and sustainability.

4.3.12. Sex ratio dynamics in *Cheyletus malaccensis* under experimental conditions

C. malaccensis follows an arrhenotokous reproductive system, where unfertilized eggs develop into haploid males and fertilized eggs yield diploid females. Under natural conditions, this mechanism typically results in a female-biased sex ratio, as females control fertilization to optimize population growth. However, the present study solely used diploid (homomorphic) males for mating and observed significant deviations from this expected trend, with sex ratios shifting toward equal under certain environmental conditions. These findings suggest that experimental manipulation of ploidy, combined with temperature and humidity stressors can disrupt the innate sex-determination system of *C. malaccensis*, contributing to a deeper understanding of how reproductive strategies in mites can adjust to changing conditions.

At 25°C, the sex ratio remained slightly female-biased (1.11:1 to 1.23:1), though still more balanced than typical arrhenotokous populations. This suggests that even under near-optimal conditions, the use of diploid males rather than haploid ones reduces the degree of female predominance. As temperatures increased to 29°C, the ratio approached near-equality (1.02:1 at 80% RH), indicating that thermal stress may interfere with fertilization efficiency or female survival. The most significant population declines occurred at 33°C, where extreme heat impacted both sexes but maintained the characteristic female-biased ratio (2:1 at 90% RH) (Table 10).

Apart from other contributing factors, the exclusive use of *Suidasia nesbitti* as a food source may not have supported optimal nutrition for maximum female egg production. Nutritional limitations are known to affect sex ratios in arrhenotokous species, as the production of diploid female offspring typically requires more resources than haploid male production (Wrensch & Ebbert, 1993). Frequent exposure to light during microscopic examination, combined with repeated disturbances from handling, egg collection, and transfer, as well as possible nutritional limitations from the prey diet, may have created stressful conditions that disrupted normal reproductive behavior, reduced mating opportunities, or led even mated females to lay unfertilized eggs at higher-than-expected rates. This demonstrates the remarkable flexibility of the reproductive strategies of *C. malaccensis*, where even mated females can be triggered by stressful environments to produce male offspring from unfertilized eggs, bypassing the expected outcome of controlled mating.

TABLE 10. Developmental traits of *Cheyletus malaccensis* under varying thermal and humidity conditions

Temperature (°C)	RH (%)	Fecundity (Mean ± SE)	Net reproductive rate (R_0,) (Mean ± SE)	Development Time (♀) in days (Mean ± SE)	Generation Time (T) in days (Mean ± SE)	Intrinsic rate of increase (r_m) (Mean ± SE)	Finite Rate of Increase (λ) (Mean ± SE)	Doubling Time (DT) in days (Mean ± SE)	Survival Rate (%) (Mean ± SE)	Sex Ratio (F:M)
25	70	292.60 ± 2.75	108.10 ± 1.84	17.12 ± 0.33	20.22 ± 0.38	0.232 ± 0.004	1.26 ± 0.005	2.99 ± 0.05	70.0 ± 0.57	1.11: 1
	80	227.40 ± 4.72	86.60 ± 3.49	22.60 ± 0.59	25.00 ± 0.69	0.180 ± 0.006	1.20 ± 0.007	3.90 ± 0.12	69.4 ± 0.93	1.23: 1
	90	172.00 ± 4.17	60.90 ± 1.73	13.60 ± 0.16	15.60 ± 0.26	0.264 ± 0.003	1.30 ± 0.005	2.63 ± 0.04	65.0 ± 0.77	1.20: 1
29	70	127.00 ± 2.63	49.80 ± 0.98	11.52 ± 0.14	14.05 ± 0.14	0.278 ± 0.003	1.32 ± 0.005	2.49 ± 0.03	75.0 ± 0.82	1.11: 1
	80	139.90 ± 2.83	55.40 ± 1.13	13.25 ± 0.12	16.01 ± 0.13	0.251 ± 0.002	1.28 ± 0.002	2.77 ± 0.02	78.2 ± 0.27	1.02: 1
	90	105.00 ± 2.99	39.90 ± 1.78	10.45 ± 0.23	12.60 ± 0.20	0.292 ± 0.005	1.34 ± 0.007	2.38 ± 0.04	70.4 ± 1.16	1.18: 1
33	70	108.00 ± 4.20	32.60 ± 2.51	11.08 ± 0.27	13.38 ± 0.35	0.260 ± 0.008	1.30 ± 0.011	2.69 ± 0.08	49.4 ± 2.62	1.57: 1
	80	120.00 ± 3.48	42.70 ± 2.21	11.60 ± 0.36	13.50 ± 0.41	0.280 ± 0.010	1.32 ± 0.014	2.51 ± 0.09	59.7 ± 1.6	1.48: 1
	90	90.00 ± 3.56	23.60 ± 2.27	10.30 ± 0.20	12.40 ± 0.37	0.253 ± 0.010	1.29 ± 0.013	2.77 ± 0.09	40.1 ± 3.29	2.00: 1

4.3.13. Morphological descriptions of developmental stages of *Cheyletus malaccensis*

PLATE 40 A, B

Egg

Eggs are pale white coloured, nearly elliptical in shape, measuring 115-135 µm in length and 70-80 µm in width. Over 1.5 days, one end becomes pointed at one end, (corresponding to the posterior part of embryo) and slightly flattened dorsally. Transverse wrinkles may appear on eggshell. As embryo matures, gnathosoma bends ventrally, with legs on ventral side. Faint white streak sometimes visible at posterior dorsal region, appears digestive tract.

Larva

Larva measures 225-320 µm in length (including the gnathosoma). Peritreme M- shaped with lateral arms bearing 6-8 segments and inner arms bearing 3-5 segments. Gnathosoma devoid of ventral setae. Palp femur equipped with one branched dorsal seta, genu features one plumose dorsal seta and lacks ventrolateral seta. Palp tarsus possesses one outer large comb seta with 10-12 teeth and one inner small comb seta with 9-12 teeth. Palp tibial claw exhibits two distinct basal processes, deeply incised. Propodosomal shield rounded anteriorly and acute posteriorly, bearing four pairs of plumose setae. Hysterosoma equipped with five pairs of dorsal setae with the second row closely spaced and adorned with transverse striations. Ventral idiosoma features two pairs of needle-like ventral setae, three pairs of needle-like anal setae, and one pair of plumose setae proximal to anal opening. Legs exhibit reduced chaetotaxy, with coxa I featuring one needle-like seta, tarsus I without terminal bifurcated setae and provided with a guard seta longer than solenidion ω. Tarsus II-III devoid of ventral setae and possess only one terminal bifurcated seta.

Protonymph

Protonymph measures 310-570 µm in length (including gnathosoma). Gnathosoma features M-shaped peritreme. Palps femur with one ventral seta (two in adults), genu without ventrolateral seta, tarsus with one outer large comb seta (14-18 teeth) and one inner small comb seta (12-15 teeth). Palp tibial claw with two deeply incised basal processes. Propodosomal shield rounded anteriorly, bearing four pairs of plumose setae and one lateral pair. Hysterosoma with five pairs of dorsal setae with oblique striations. Ventrum with three pairs of needle-like ventral setae and three pairs of anal setae (one needle-like and two bifurcated). Trochanter of leg III with one ventral seta (two in deutonymph/adults), femur III possesses one dorsal seta (two in later stages). Tarsus I equipped with one guard seta, longer than solenidion *ω* (as in the larva).

Deutonymph

Deutonymph measures 418-596 µm in length (including gnathosoma). Palps tarsus bears one outer large comb seta (20-24 teeth) and one inner small comb seta (16-18 teeth) along with one tibial claw featuring two clearly separated basal processes. Propodosomal shield almost square shaped, with five pairs of plumose setae and one lateral pair. Hysterosoma with eight pairs of dorsal setae and one additional ventral pair proximal to anus. Ventral idiosoma with six pairs of ventral setae (including one pre-anal pair) and three pairs of anal setae (one needle-like and two broadly plumose). Legs chaetotaxy nearly identical to adults, with tarsus I featuring a guard seta longer than solenidion *ω*.

Adult Male

Adult male measures 405-605 µm in length (including gnathosoma). Peritreme arch shaped (vs M-shaped peritreme in female). Rostrum with distinctive wing-like lateral projections. Length of palpal femur variable, with a ratio of 1.3-2.9 (shorter forms exhibit pronounced condyles). Palp tarsus bears one large outer comb seta with 13-15 teeth and one inner small comb seta with 8-11 teeth. Propodosomal shield broad, bearing six pairs of plumose setae. Hysterosomal shield extends to the anal region and equipped with six pairs of setae. Ventral idiosoma with three pairs of genito-anal setae (one hook-like, one plumose, and one needle-like) along with a funneliform aedeagus. Legs possess solenidia (*ω*, *φ*) on tarsus I conspicuously larger than those of adult female.

Adult Female

Adult female measures 635-835 µm in length (including gnathosoma). Peritreme M-shaped. Palp femur with two ventral setae (one branched and one needle-like). Palp tarsus bears one large outer comb seta with 18-20 teeth and one inner small comb seta with 24-30 teeth. Tibial claw with a single basal process (variable). Propodosomal shield with four pairs of marginal setae and one scapular pair. Hysterosomal shield features three pairs of setae. Ventral idiosoma bears six pairs of ventral setae and two pairs of genital setae. Guard seta of tarsus I shorter than solenidion *ω* (guard seta is longer in immature forms).

PLATE 40 A

Developmental stages of *Cheyletus malaccensis* Oudemans, 1903

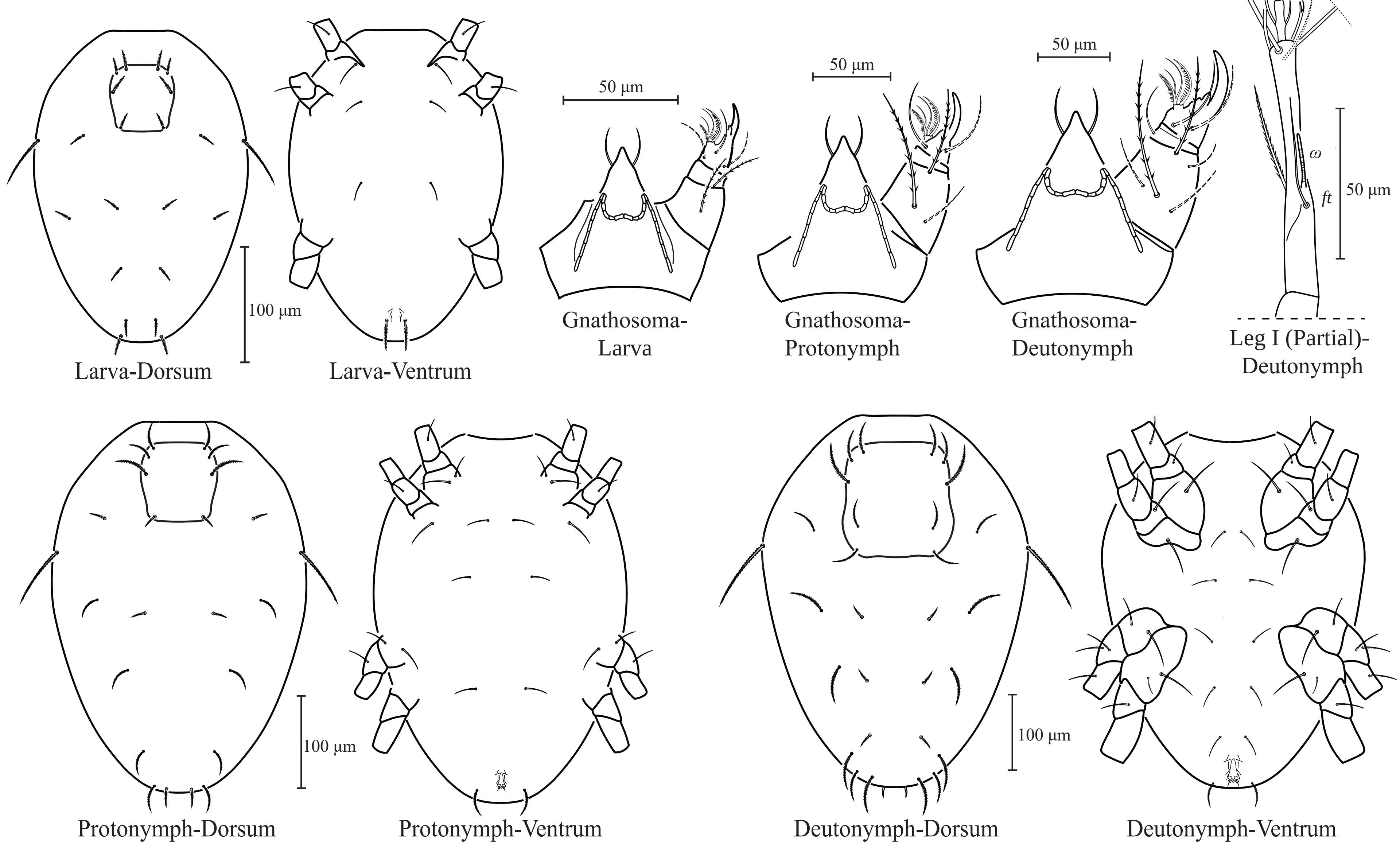
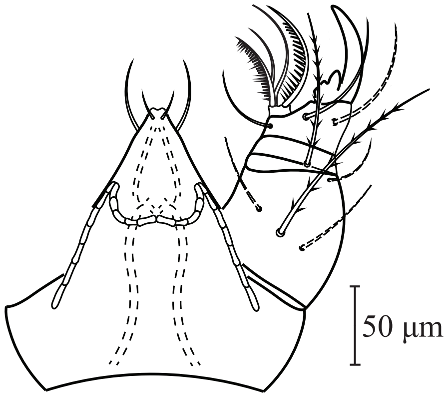
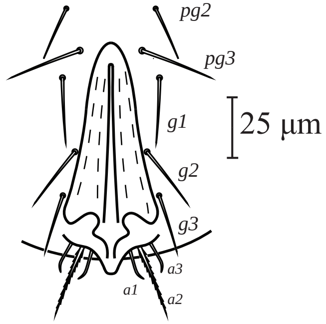


PLATE 40 B

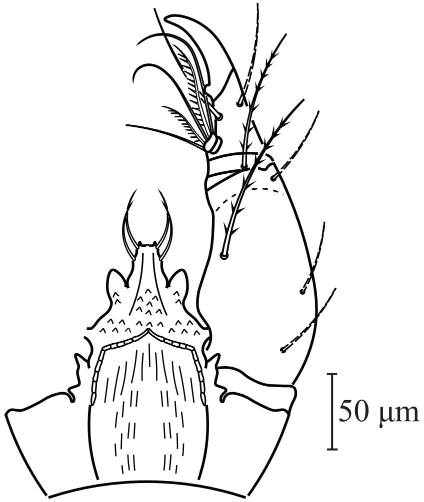
Developmental stages of *Cheyletus malaccensis* Oudemans, 1903



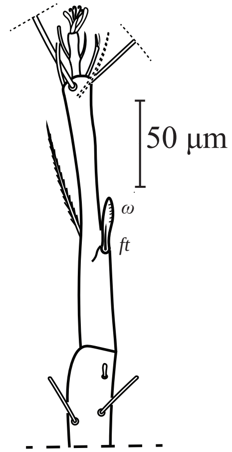
Adult Female-Gnathosoma



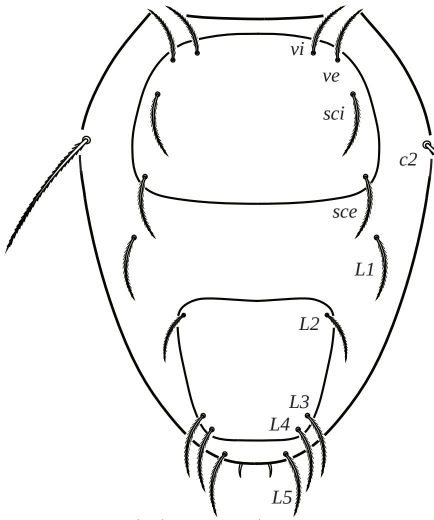
Adult Female-Genito-anal region



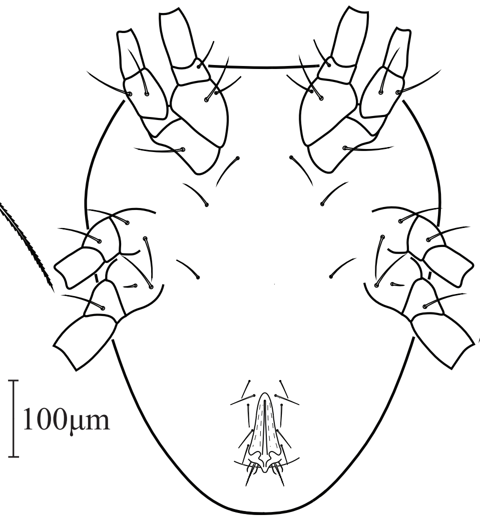
Adult Male-Gnathosoma



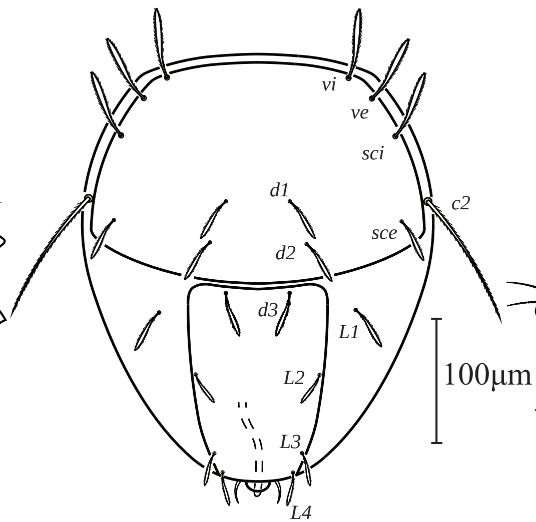
Adult Male-Leg I (Partial)



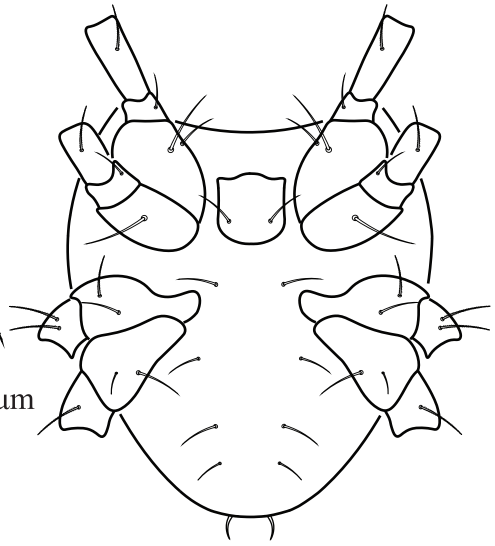
Adult Female-Dorsum



Adult Female- Ventrum



Adult Male-Dorsum



Adult Male-Ventrum

4.3.14. Brief morphological description and developmental biology of *Suidasia nesbitti* Hughes, 1948

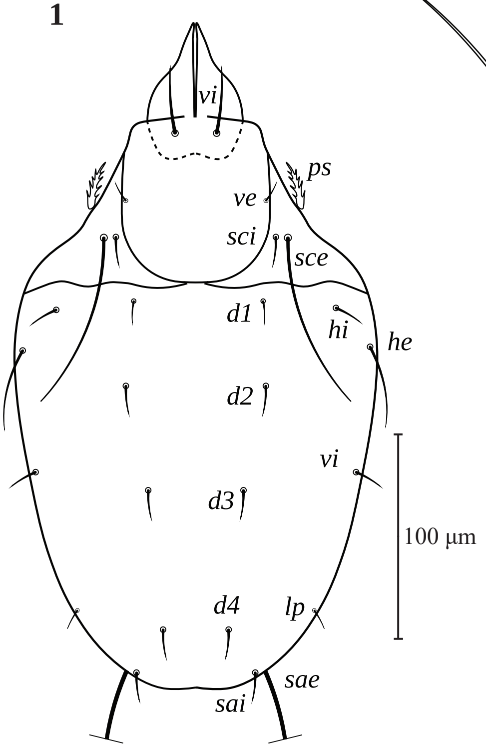
PLATE 41

Description: Length of idiosoma ranges from 260 to 340 µm (male: 260-300 µm; female: 300-340 µm). Idiosoma broadly oval and ornamented with longitudinal grooves and wrinkles. Propodosomal shield smooth, extends posteriorly to the hysterosomal boundary, with no overlap. Setae *vi* forwardly extended over gnathosoma. Setae *ve* short, positioned at the mid-lateral margin of propodosomal shield. Supracoxal seta flattened, bearing marginal pectinations. Setae *sce* located proximal to *sci*; four times longer than *sci*. All dorsal hysterosomal setae short except *he* and *sae* (*sae* spanning half of the idiosomal length). Setae *d1* to *d4* linearly arranged. Setae *sci* similar in length with *he* and *sae*. Apodemes broad and stout. In females, anal opening reaches posterior margin of body, surrounded by five pairs of anal setae; third pair of setae being further from the anus than the others. Genital opening extends between coxae III and IV. In males, anal opening reaches posterior margin of body; surrounded by three pairs of anal setae. Chelicera bears toothed shears and a mandibular spine ventrally. Legs short, chaetotaxy same in both sexes. Setae *d* on leg I projects beyond terminal claw. Setae *e* and *f* reduced, solenidion *ω* curved, rod like. Setae *p*, *q* and *s* conspicuous, with bent spiniform morphology; setae *s* medially positioned on tarsus. Setae *u* and *v* long, narrow and appressed against pretarsus.

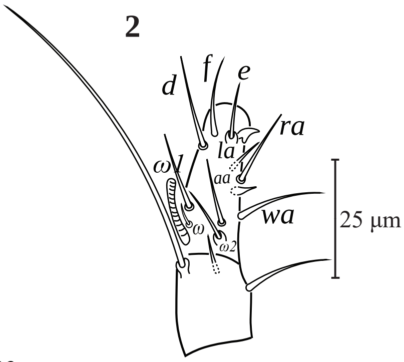
Developmental Biology: Under optimized rearing conditions of 29 ± 1.5°C and 80 ± 5% relative humidity, *Suidasia nesbitti* demonstrated rapid development, with female mites completing their life cycle from egg to adult within 14.2 ± 0.29 days. The development progressed through five distinct active stages viz., egg, larva, protonymph, tritonymph, and adult, while the deutonymph phase remained absent under these controlled conditions, though previous studies reported its occurrence during environmental stress. Adult females exhibited robust reproductive capacity, laying an average of 120 ± 1.42 eggs during their lifespan. The reproductive cycle consisted of a 2.1 ± 0.12-day pre-oviposition period, followed by a productive 25 ± 0.50-day oviposition period, and concluded with a 4.2 ± 0.34-day post-oviposition phase. The lifespan of males was 36 ± 0.56 days, while females lived significantly longer, with an average lifespan of 45.5 ± 0.35 days under maintained laboratory conditions. Across all developmental stages, the population maintained a consistent 25% mortality rate.

PLATE 41

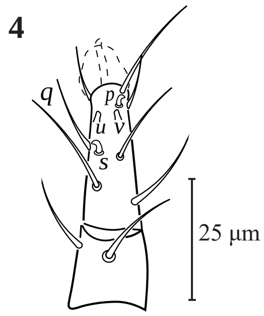
Figure 1-10. Morphology and developmental stages of *Suidasia nesbitti* Hughes, 1948



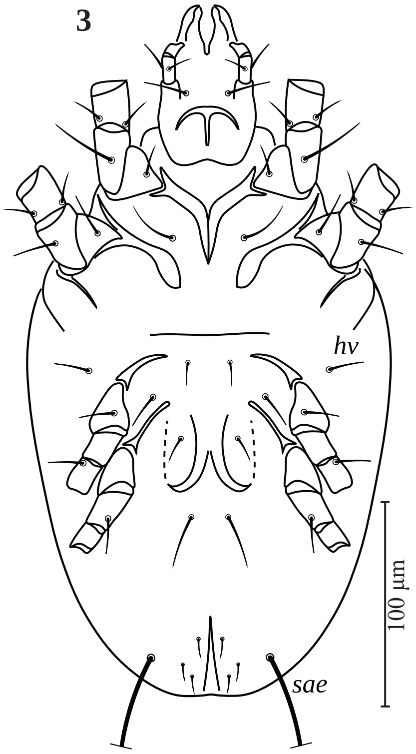
1. Dorsum
(Adult female)



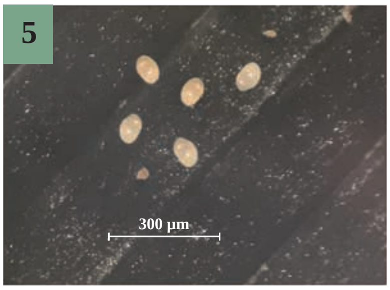
2. Leg I- tarsus & tibia
(dorsal view-right leg)



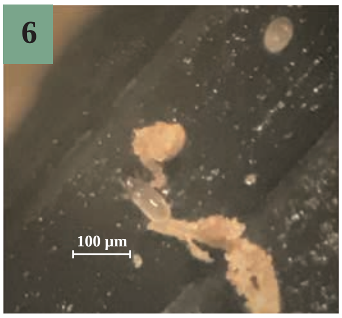
3. Leg I- tarsus & tibia
(ventral view-left leg)



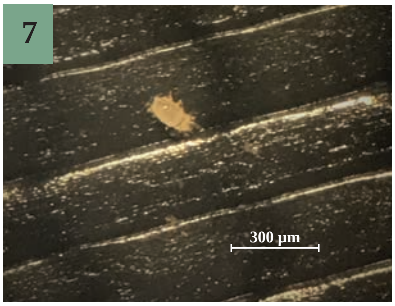
4. Ventrum
(Adult female)



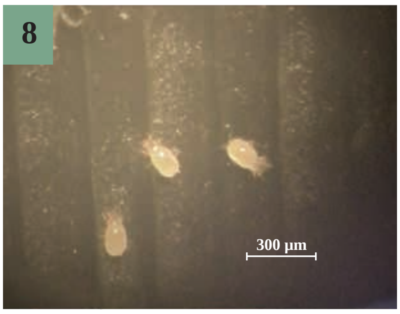
5. Egg



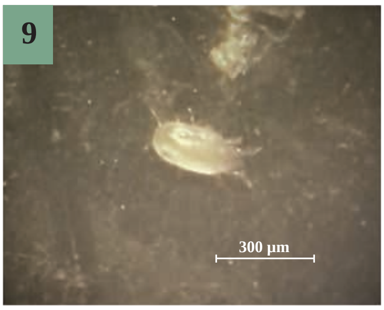
6. Larva



7. Protonymph



8. Tritonymph

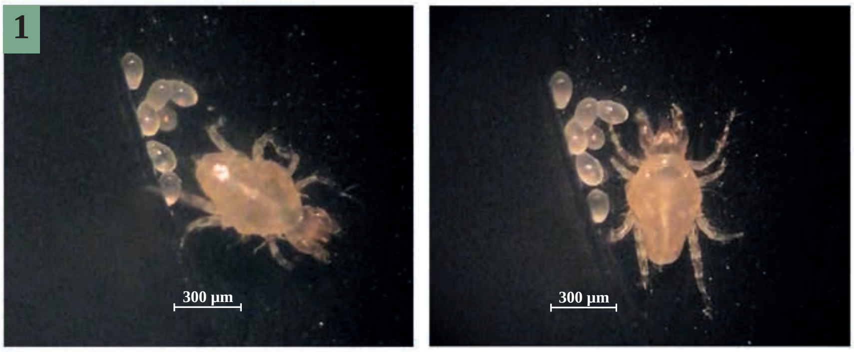


9. Adult male

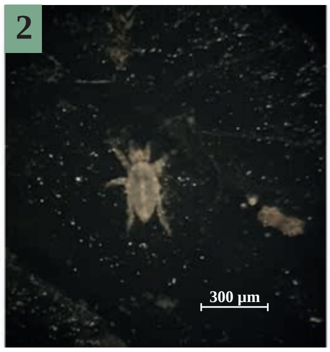
10. Adult female

PLATE 42

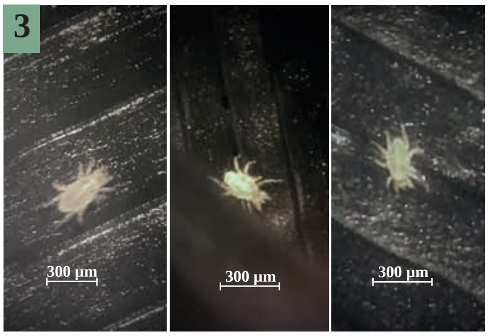
Figure 1-12. Developmental stages and feeding behavior of *Cheyletus malaccensis*



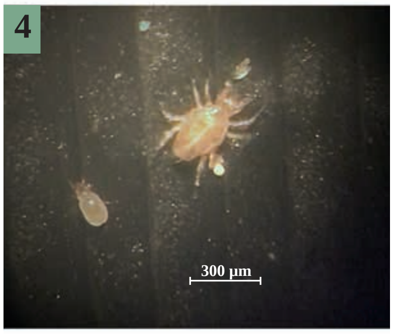
1. Oviposition and egg guarding by adult female *C. malaccensis*



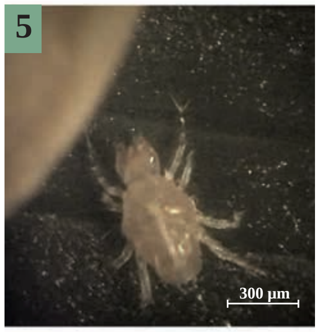
2. Larva



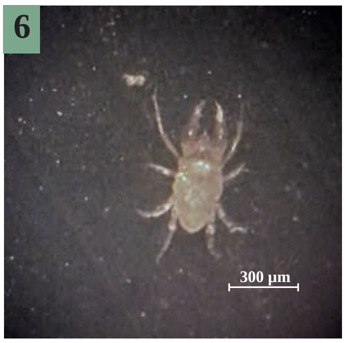
3. Protonymph



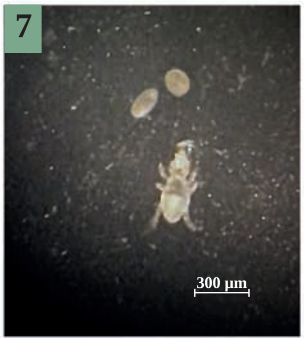
4. Deutonymph



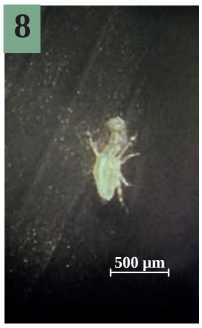
5. Adult Female



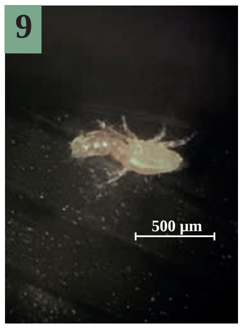
6. Adult Male



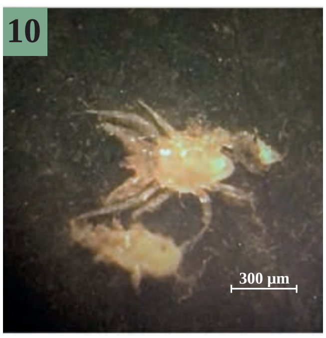
7. Larva of *C. malaccensis* feeding on eggs of *Suidasia nesbitti*



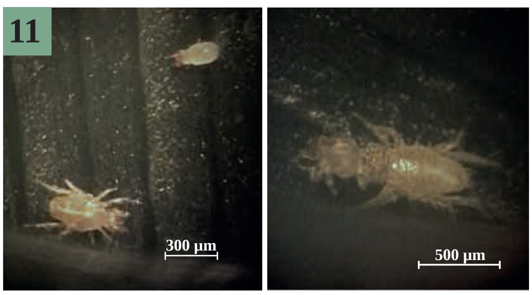
8. Protonymph of *C. malaccensis* feeding on *S. nesbitti* larva



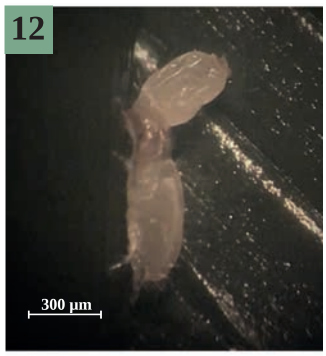
9. Deutonymph of *C. malaccensis* feeding on *S. nesbitti* tritonymph



10. Adult male *C. malaccensis* with partially fed adult male *S. nesbitti*



11. Foraging and predatory behavior of adult female *C. malaccensis*



12. Adult female of *C. malaccensis* feeding adult female *S. nesbitti*

4.3.15. Feeding Biology of *Cheyletus malaccensis* (Oudemans, 1903)

Feeding potential of five different developmental stages of the predatory mite *Cheyletus malaccensis* (Plate 42) was assessed using six distinct life stages of the prey mite *Suidasia nesbitti*. The experiments were conducted under controlled conditions at 29 ± 1°C and 80 ± 5% relative humidity. Rapid growth and the maximum adult survival rate were observed at this temperature and humidity condition; hence, it was selected for the study.

Cheyletus malaccensis exhibited robust and rapid movement when introduced into the 3D printed rearing Petri dish, displaying escape behavior and a distinct preference for darkness (photophobic response). The mites actively sought shelter in shaded areas to avoid light exposure from the stereozoom microscope. All developmental stages, from larva to adult, demonstrated high mobility, and their movement intensified as the predator matured.

Prior to experimentation, a 24-hour starvation period was imposed to standardize hunger levels. Following this, 20 individuals from different prey stages (egg, larva, protonymph, tritonymph, adult male, and adult female) were offered to various stages of the predatory mite (larva, protonymph, deutonymph, adult male, and adult female) according to the experimental design, and feeding responses were recorded over a 24-hour period. Initially, the predatory mites did not exhibit immediate attack behavior. However, after a brief 5-minute dark period (induced by dimming the light from microscope), they began actively attempting to capture the prey. *Cheyletus malaccensis* possesses sensory setae on tarsus I, which it uses to first make contact with the prey. Upon detection, the predator rapidly captured the prey using its forward-directed legs I and II. The powerful chelicerae then firmly immobilized the prey, allowing the mite to pierce and extract internal fluids using its mouthparts (Plate 42, Figure 12).

During feeding, *C. malaccensis* frequently lifted the prey and occasionally relocated it before consumption. The prey mite *Suidasia nesbitti*, especially in its adult form exhibits an oval and distended body structure, primarily attributed to the internal fluids. Observations revealed that when female predators attacked adult female prey, they typically pierced their bodies, after which the predator extracted the swollen internal fluids. The rhythmic extraction process was distinctly observable, leading to a significant reduction in the prey's body size, which resembled that of a dried raisin. These observations suggest the presence of robust pharyngeal muscles in *C. malaccensis*.

The larval and nymphal stages of the predator predominantly targeted the eggs and larvae of the prey, employing the same piercing and sucking feeding mechanism. Among all predatory stages, the adult female exhibited the highest feeding efficiency, whereas the larval stage of the prey was identified as the most vulnerable. These findings suggest that the most effective prey suppression occurs during the early developmental stages, with adult predators contributing the greatest predation efficiency.

All findings were statistically validated, and detailed feeding responses are represented through feeding matrix (Plate 43). Furthermore, in a separate observation conducted outside the main experimental design, prolonged starvation in *Cheyletus malaccensis* led to the emergence of cannibalistic behavior, indicating a potential survival strategy under extreme food deprivation.

C. malaccensis exhibits distinct stage-specific predation efficiency when feeding on different developmental stages of the prey mite *Suidasia nesbitti*. The interaction between predator and prey life stages reveals a clear hierarchy in both predatory effectiveness and prey susceptibility shaped by morphological, behavioural and ecological constraints.

4.3.15.1. Predator efficiency

Among all developmental stages of *Cheyletus malaccensis*, adult females exhibited the highest feeding efficiency, consuming a broad range of prey stages at notably high rates: eggs (1.80 ± 0.36), larvae (13.20 ± 0.65), protonymphs (9.50 ± 0.34), tritonymphs (9.00 ± 0.42), adult males (3.60 ± 0.27), and adult females (2.80 ± 0.24). This predatory performance was significantly greater than that of all other stages (Tukey HSD, $p < 0.001$)

Adult males followed in efficiency, showing strong predation on larvae (11.50 ± 0.48), protonymphs (9.00 ± 0.42), and tritonymphs (9.20 ± 0.25) stages, with lower consumption of eggs (1.40 ± 0.27), adult males (2.40 ± 0.12), and adult females (2.20 ± 0.15) prey (Plate 42).

Deutonymphs primarily consumed larvae (9.90 ± 0.41) and protonymphs (7.20 ± 0.39) at high rates, followed by tritonymphs (7.20 ± 0.36), while showing reduced consumption of eggs (2.20 ± 0.25), adult males (1.90 ± 0.33), and adult females (0.60 ± 0.12) prey.

Protonymphs were moderately efficient and preferred consuming larvae (9.00 ± 0.37), protonymphs (6.50 ± 0.34), and tritonymphs (5.10 ± 0.28), but with reduced predation on eggs (3.20 ± 0.36), adult males (1.50 ± 0.25), and adult females (0.40 ± 0.12).

Larvae exhibited the lowest feeding efficiency, with prey consumption rates declining sharply with increasing prey stage. They consumed eggs (8.00 ± 0.33) and larvae (7.00 ± 0.39) relatively well, but predation efficiency dropped for protonymphs (5.00 ± 0.30), tritonymphs (2.50 ± 0.31), adult males (0.20 ± 0.08), and adult females (0.00 ± 0.00) prey.

The statistical significance of differences in consumption patterns among predator stages was confirmed by a two-way ANOVA ($F = 79.476$, $p < 0.001$, partial $\eta^2 = 0.541$). Post hoc Tukey HSD comparisons revealed a clear, statistically supported hierarchy in predatory efficiency: Adult female > Adult male > Deutonymph > Protonymph > Larva.

The superior predatory efficiency of adult females is likely due to their larger size, strong chelicera, and enhanced mobility, as well as increased foraging drive associated with reproductive needs. In contrast, the lower performance of larvae and protonymphs can be attributed to underdeveloped morphology and reduced hunting experience.

4.3.15.2. Prey vulnerability

The larval stage of *Suidasia nesbitti* was the most vulnerable to predation, with high mean consumption rates across predator stages, such as by adult females (13.20 ± 0.65), adult males (11.50 ± 0.48), deutonymphs (9.90 ± 0.41), and protonymphs (9.00 ± 0.37). Even larval predators consumed larval prey at a notable rate (7.00 ± 0.39).

Following the larvae, protonymphs were the next most susceptible stage, which were consumed in large numbers by adult females (9.50 ± 0.34), adult males (9.00 ± 0.42), and deutonymphs (7.20 ± 0.39). Tritonymphs followed closely, with high predation from adult males (9.20 ± 0.25) and deutonymphs (7.20 ± 0.36) (Plate 42).

In contrast, egg predation was more variable. While larval predators consumed them at high rates (8.00 ± 0.33), adult females and males consumed fewer eggs (1.80 ± 0.36 and 1.40 ± 0.27, respectively), suggesting selectivity based on predator stage.

Adult prey were the least consumed stages overall, especially adult females, with recorded mean consumption ranging from 0.00 ± 0.00 (larval predators) to 2.80 ± 0.24 (adult female predators). Adult males were also less vulnerable, with consumption rates of 2.40 ± 0.12 (by adult male predators) and 3.60 ± 0.27 (by adult predator female predators).

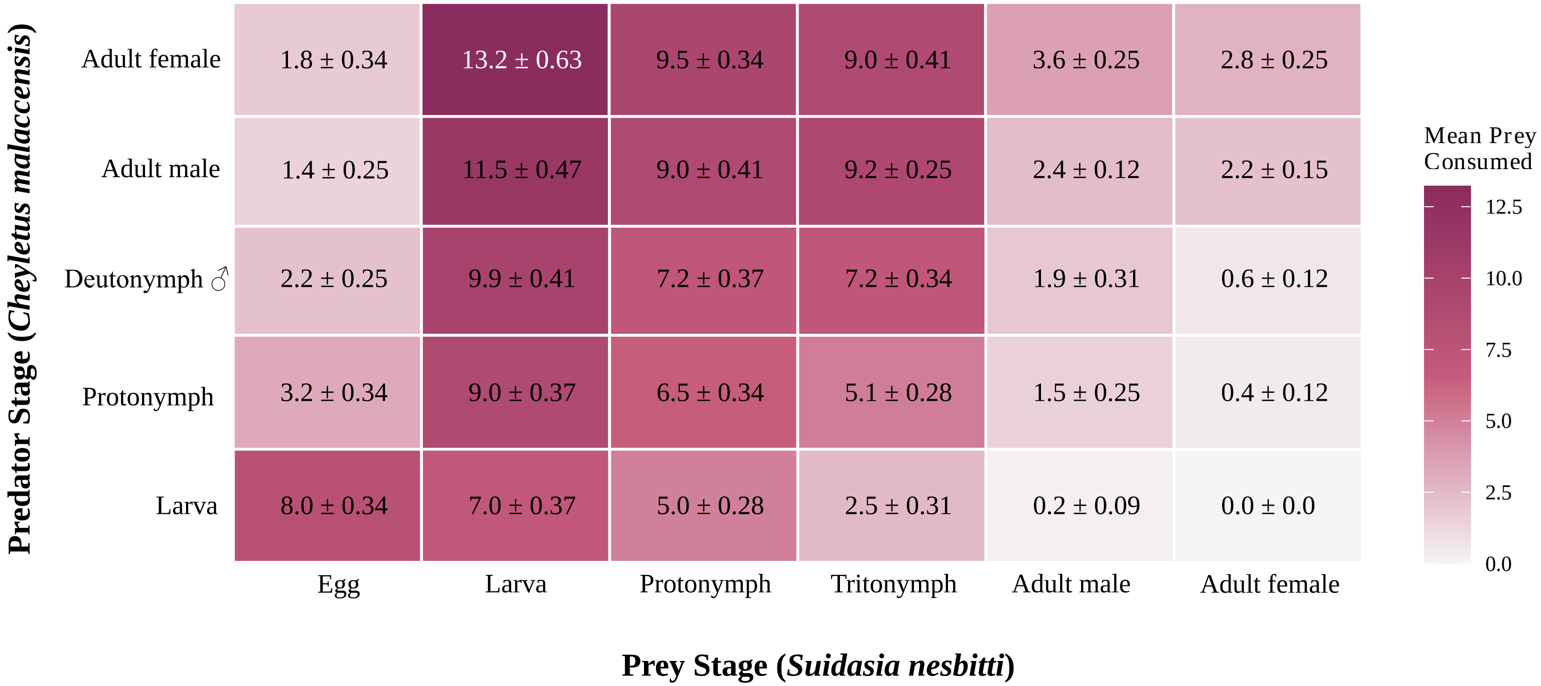
These patterns were strongly supported by statistical analysis. A highly significant main effect of prey stage was observed ($F = 581.435$, $p < 0.001$, partial $\eta^2 = 0.915$). Tukey HSD tests confirmed significant pairwise differences among all prey stages, establishing the following vulnerability hierarchy: Larva > Protonymph > Tritonymph > Egg > Adult male > Adult female.

The higher susceptibility of larvae likely results from their lightly sclerotized body, slow movement, and lack of defensive behaviors, making them easy and energy-efficient targets. On the other hand, adult prey, particularly females, are better defended due to their hardened cuticles and higher mobility, contributing to their lower overall consumption rates. However, this lower predation does not necessarily indicate a lack of preference, especially among adult predators. Consuming even one or two adult prey within 24 hours may provide sufficient nutrition and energy to meet their metabolic needs, thereby reducing hunger and the necessity for frequent hunting. While prey eggs are immobile and nutritionally dense, their extremely small size means that each individual egg provides only a minimal nutrient yield, making them a less efficient food source and requiring predators to consume many to meet their nutritional needs.

PLATE 43

Figure A. Predation matrix (Mean ± SE)

(Prey offered = 20 | Duration = 24 Hours | n = 10)



4.4. Mass Rearing of *Cheyletus malaccensis* (Oudemans, 1903)

The predatory mite *Cheyletus malaccensis* was mass-reared using *Suidasia nesbitti* as its prey source at 29°C and 80% RH. The mass-rearing experiment demonstrated remarkable population growth of *Cheyletus malaccensis* during the initial 30-day period, with predator numbers increasing 36.5-fold to reach 14,650 ± 2,840 individuals per rearing container (Table 11). However, extended rearing to 60 days revealed significant growth inhibition, yielding only 5,380 ± 2,812 mites, resulting in a substantially reduced 13.45-fold multiplication rate. This decline in productivity was attributed to two primary factors that collectively degraded rearing conditions over time. First, the accumulation of nitrogenous waste products became increasingly problematic as both prey and predator mites excreted uric acid, which under the maintained humid conditions (80 ± 5% RH) underwent chemical breakdown into volatile ammonia compounds. The persistent ammonia odour detected in older cultures served as a clear indicator of this progressive environmental deterioration. Second, although the number of prey offered weekly remained constant until the 60th day, the rapidly growing predator population likely required more prey, potentially leading to increased competition and cannibalistic behavior. Consequently, *C. malaccensis* adults increasingly preyed on juveniles and eggs as population densities rose. These findings highlight the importance of maintaining rearing periods below 60 days and implementing periodic colony renewal to avoid the detrimental effects of waste accumulation and cannibalism.

In tropical regions, mass rearing at a constant 25°C typically requires substantial electricity and costly equipment, such as environmental chambers. However, in locations where ambient conditions average around 29°C and 80% relative humidity (RH) year-round, as in the present study, this methodology becomes particularly advantageous, reducing the need for energy-intensive cooling and humidification.

TABLE 11. Population growth dynamics of *Cheyletus malaccensis*

Rearing Period in days	Population Count (Mean ± SD)	Fold Increase	Key Observations
30	14,650 ± 2,840	36.5x	Peak productivity
60	5,380 ± 2,812	13.45x	Significant decline due to waste accumulation/cannibalism

CHAPTER V

DISCUSSION

5. DISCUSSION

5.1. Part I- Taxonomy

The study surveyed 61 storage facilities across six districts of North Kerala, namely Kasaragod, Kannur, Kozhikode, Wayanad, Malappuram, and Palakkad, from which a total of 63 edible stored products were examined. The results from the study revealed 28 species of predatory mites, belonging to 19 genera, 13 families and two orders. The recorded species distribution across taxa appeared varied as the aim of the study encompassed the general collection of all available predatory mites from stored products rather than focusing on any specific taxonomic group. While the number of obtained families and genera was significant, the corresponding species richness within these higher taxonomic levels was not proportionally high. A primary factor contributing to this observation is likely the widespread and routine application of broad-spectrum pesticides and fumigants within storage facilities. These control measures, intended for rodents, insect pests, and mites likely suppress predatory mite populations. The abundance of predatory mite species collected was notably low when compared to the overall weight of each collected sample.

The family Laelapidae was represented by three genera, from which four species were recorded, indicating a comparatively higher generic diversity within the limits of this study. A recent checklist of Indian laelapid mites by Bandyopadhyay *et al*. (2023) documented 66 species across 21 genera from various habitats; nevertheless, specific data on species inhabiting stored products were not provided. It is important to consider that, laelapids are associated with various habitats including soil, leaf litter, plants, arthropods, birds and mammals (Lindquist et al., 2009, Moraes et al., 2022). Interestingly, when comparing the documented species included in the checklist by Bandyopadhyay *et al*. (2023), it is noteworthy that they did not report two laelapid species obtained from the present study, namely *Stratiolaelaps scimitus* and *Euandrolaelaps karawaiewi*. This suggests that the present work is reporting these species from India for the first time. Furthermore, the incidence of four laelapid mite species inhabiting stored products in North Kerala, obtained from the present study, holds much significance when considered against the overall size and biodiversity of India, despite this small number. Moreover, the listed laelapid mites are very potent predatory mites.

Based on recent literature, the family Stigmaeidae is an extensive taxon, comprising over 635 described species across 33 genera (Khaustov, 2021). The species of the family

Stigmaeidae inhabits a wide range of environments. The present study identified a single genus from this family *viz*., *Storchia*. The occurrence of *Storchia* is of particular interest as this genus was not previously known to be native to India. Currently, *Storchia* includes 12 species primarily distributed in China, Iran, and Turkey (Fan et al., 2019). In this study, the genus *Storchia* was represented by only one species *viz*., *Storchia pacifica*. While Seeman *et al*. (2023) reported the presence of *Storchia pacifica* with an Indian origin, this record originated from specimens intercepted by Australian quarantine and inspection services during examination of Indian exported stored products in Australia. Moreover, this finding, based on interception in Australia rather than collection within India, does not definitively confirm a native Indian occurrence and raises the possibility of infestation during transportation, thus remaining questionable. In addition, they reported an asymmetrical variation in Indian specimens, characterized by three genital setae on the left side and two on the right; however, such variation has not been observed in the specimens examined in this study. This discrepancy further strengthens doubts about the exact origin of their species, especially considering they did not provide a precise collection location. Therefore, in accordance with the results from the present study, the documentation of the genus *Storchia*, along with the redescription of *Storchia pacifica* and the provision of a key to the world species (which was not previously available), can be considered the authentic record and first report of this genus in India.

Among the 63 stored products examined, boiled rice harboured the highest number of mite species (11), followed by raw rice (10) and wheat (7). These cereals are staple and widely consumed grains throughout India. Regarding storage facilities, the warehouse situated within the market in Kozhikode district (also known as Valiyangadi) exhibited the greatest species richness among the warehouses, with a total of 5 mite species identified. This lower number, despite the greater variety of commodities (13) sampled from this storage facility, is noteworthy. This extensive market place spans approximately one kilometre and serves as a significant hub for both import and export activities in North Kerala. However, surveying every store and warehouse within this market was not feasible due to limitations in obtaining consent for sampling from numerous owners. In contrast to the market warehouse, the Food Corporation of India (FCI) warehouses, despite storing thousands of metric tonnes of products, primarily contained only a limited variety: raw rice, boiled rice, wheat, and fortified rice. Consequently, no FCI warehouse contained more than 3 mite species. The most prevalent species across all FCI warehouses in North Kerala were *Cheyletus malaccensis* and *Blattisocius* *keegani*, with *C. malaccensis* predominantly found in stored wheat and *B. keegani* prevalent in boiled rice within these facilities.

Upon reviewing some important surveys on stored product mites in India (Putatunda, 2004; Gupta and Chatterjee, 2004; Jain et al., 2005; Chakraborty and Gupta, 2016; Gill and Dehar, 2018) reveals a prevalence of pest mite species. Notably, none of these studies documented more than 10 predatory mite species clearly identified to the species level across India in their surveys. This suggests that many predatory mite species associated with stored products are not ubiquitous, dominant, or frequently encountered, but rather occur occasionally. Obtaining such low-incidence predatory mites can be challenging, sometimes requiring extensive investigation. However, certain species, such as *Cheyletus malaccensis*, *Cheyletus eruditus*, *Blattisocius keegani*, *Blattisocius tarsalis*, *Cunaxa capreolus*, *Cunaxa setirostris*, and *Androlaelaps casalis,* appear to be more readily found across various locations.

Cheyletid mites are ubiquitous and dominant, primarily free-living predators that feed on various small arthropods, pest mites, and the eggs of stored-product pest insects (Zdarkova, 1979, 1998). Their frequent presence in warehouses and other storage facilities is well-documented (Hughes, 1976). Species belonging to the genus *Cheyletus* are often used as effective biological control agents against stored-product mite pests. The natural co-occurrence of *Cheyletus* mites with several prey species suggests their broad prey range (Cebolla et al., 2009).

Regarding the findings of the present study, family Cheyletidae was represented by two genera: *Acaropsella* and *Cheyletus*, comprising a total of five species. Surveys conducted globally over the past seven decades have consistently documented *Cheyletus* mites, establishing it as a dominant genus, with *Cheyletus malaccensis* and *Cheyletus eruditus* being key contributors to this dominance. Analysis of the present results revealed that *Cheyletus malaccensis* was recorded from 52 out of 61 storage facilities indicating its widespread incidence. According to the numerous publications and survey reports from India, the occurrence of the genus *Cheyletus* is not unexpected.

However, the finding of the genus *Acaropsella*, belonging to the same family, presents a fascinating observation. This genus has not been previously reported from India and comprises only nine described species worldwide (Martin and James, 2023). In the present work, this genus was represented by a single species, namely *Acaropsella strioreticulata*. Therefore, this discovery can be considered a valuable contribution to the cheyletid fauna of India, especially considering their potential as powerful predatory mites.

Similar to the prevalence of Cheyletid mites, species belonging to the genus *Blattisocius* are commonly encountered in stored products. These potent predators effectively prey upon the eggs and larvae of pest insects and mites. Within the present study, the family Blattisocidae was represented by two genera: *Blattisocius* and *Hoploseius*. The genus *Blattisocius* encompasses 16 described species globally (Moraes et al., 2016). Among this genus, three species were recorded in this investigation, viz., *Blattisocius dentriticus* Berlese, *Blattisocius keegani* Fox, and *Blattisocius tarsalis* (Ewing). These three species are recognized as common, frequently encountered, and extensively studied predatory mites associated with stored products (Thomas et al., 2011). Therefore, their occurrence in stored products is well-established, and the present study corroborates this finding.

In contrast, a striking observation was the occurrence of the genus *Hoploseius*. These mites are typically found in association with fungal fruiting bodies (Faraji et al., 2006), and their presence has not been previously documented in typical stored products worldwide. However, the *Hoploseius* species recorded in the present study, *Hoploseius andamensis* Bhattacharyya, 2002, was collected from stored edible oyster mushrooms. This finding aligns with the association reported by Faraji *et al*. (2006). It is important to note that edible oyster mushrooms possess a relatively short shelf life (7-10 days) compared to conventional stored products and thus might not be considered a typical stored commodity. Nevertheless, *Hoploseius* mites are predatory, and their efficiency could be evaluated and potentially utilized in such short-shelf-life stored products. Approximately 10 species of *Hoploseius* have been described globally. *H. andamensis* was originally described from leaf litter in the Andaman and Nicobar Islands (Bhattacharyya, 2002). Its occurrence has not been reported from mainland India since its initial discovery. This observation from the present study therefore represents a noteworthy finding.

The family Cunaxidae, particularly members of the genus *Cunaxa* such as *Cunaxa setirostris* and *Cunaxa capreolus*, exhibits a prevalent and well-established presence in stored products and plants, similar to the dominance of Cheyletid and Blattisociid species. Cunaxid mites are common and frequently encountered predators in forest systems, agricultural fields, and human habitats (Skvarla et al., 2014). The present findings indicate that this family is represented by two genera. Within *Scutopalus*, the species *Scutopalus pradhani* Gupta, 1985, was redescribed due to a lack of detailed information and proper illustrations. This genus has not been reported from Kerala so far, and there have been no Indian records since its initial discovery, remaining undocumented for the past 40 years.

The present study yielded some novel reports from the superfamily Raphignathoidea. Among these, *Paraneognathus wangae* belonging to the family Calligonellidae represents a new record for the Indian predatory mite fauna associated with stored products. The occurrence of *Paraneognathus wangae* is not unexpected, as this species has already been recorded from Iran in association with cereal stores and rice husk (Ardeshir et al., 2014). It is a very small genus with only five described species. The other member of this superfamily, *Raphignathus neocardinalis* belonging to the family Raphignathidae, was also found to be a new record for India across all habitats.

The genus *Spinibdella* was previously known from India by *Spinibdella atyeoi* described from West Bengal (Gupta & Paul, 1985). The species gathered during the survey, *viz*., *Spinibdella ampulla* and *Spinibdella tabarii* are new records for the country, with a limited occurrence and distribution of these species within North Kerala.

The family Melicharidae was represented by one genus, *Proctolaelaps*, which is a diverse and cosmopolitan group with 135 described species (Moraes et al., 2016). Within this genus, two species were collected viz., *Proctolaelaps pygmaeus* and *P. bickleyi*. Among which, *P. pygmaeus* is a common predatory mite species found in decaying plant parts, soil and stored products in India. The occurrence of *Proctolaelaps bickleyi* exhibits a comparatively lower incidence in stored product systems in India.

The superfamily Erythraeoidea obtained from the study involved two families, *viz*., Erythraeidae and Smarididae. Mites belonging to the family Erythraeidae are known from India, with some reports of their incidence in plants and to a lesser extent in stored products (Gupta, 1985). However, the genus *Balaustium* has not been documented in India; Thus, its documentation in this study establishes a new record for the country. The genus *Fessonia*, belonging to the family Smarididae, was represented by *Fessonia indica* Martin and James, 2023. This species was discovered and described as new to science during the present survey period. Before this discovery, only two *Fessonia* species were known from India (Zhang, 2003) and reports about this genus were unavailable from any habitat for the 70 years following the initial discovery of *Fessonia assmuthi* from Mumbai (Oudemans, 1941) indicating its rare occurrence.

The family Sejidae comprises free-living predatory mites commonly associated with rotten wood and leaf litter (Lekveishvili and Klompen, 2004), with their occurrence in stored products being very rare and not previously recorded elsewhere. The present survey recorded *Sejus carolinensis*, which is a new report for India. Apart from the discovery of *Sejus rufomaculata* from Tamil Nadu (Ramaraju, 2007) and the recent report of *Sejus togatus* from West Bengal (Parveen and Gupta, 2020), there are almost no other records of *Sejus* species known from India.

Hughes' (1976) comprehensive book on the mites of stored food and houses can be considered as a foundational work in stored product acarology, documenting 30 predatory mite species from various edible commodities. A comparison between the present study and the findings of Hughes (1976) revealed 12 predatory mite species in common. An interesting observation in both collections is the incidence of Phytoseiid mites, which are generally uncommon in stored products. Hughes (1976) reported one *Amblyseius* species from stored barley, and similarly, Mary Anitha (2006) reported *Amblyseius coffeae* from stored coffee berries. Smiley (1984) also supports the occasional occurrence of phytoseiid mites in stored products. The present study reports *Amblyseius indirae* Gupta 1985 from stored pepper at two different locations in the Wayanad district of North Kerala. This finding provides further confirmation that *Amblyseius* species can occur in stored products. Furthermore, it is evident that Phytoseiid mites, particularly those belonging to the genus *Amblyseius*, are important biological control agents against tetranychid and various pest insects (McMurtry and Rodriguez, 1989). Therefore, further investigation is needed to evaluate their predatory potential in both field and stored environments.

In summary, the present study reports 5 genera and 11 species as new records for the Indian predatory acarine fauna, including two newly described species. This was confirmed through extensive examination of available publications, catalogues and PhD theses from India as well as publications by foreign researchers on Indian species. The occurrence of both rarely encountered predatory mite species as well as already established dominant predatory mite species obtained from stored products in North Kerala reveals a naturally rich reservoir of biological control agents. Strategic utilization of these natural predators, integrated with sustainable and eco-friendly control measures, offers a promising approach for mitigating infestations of pest mites and insects, which in turn will reduce the necessity for extensive chemical pesticide application.

Overall, the present survey yielded 28 species of predatory mites belonging to 19 genera and 13 families from stored products in North Kerala, with several species and genera recorded for the first time from India. The wide taxonomic spread relative to the modest species count suggests that a much larger assemblage of predatory mites is likely present in these habitats but remains undetected. The low number of species per genus (generally 1-2) may be partly attributable to the inherently high mobility of predatory mites in stored-product environments. Many of these species are known to move rapidly within and between microhabitats in search of prey, which makes their capture during standard sampling particularly challenging. Given that only 100-200 g of stored product could be collected from each location due to practical constraints, it is highly probable that the actual diversity and abundance were underestimated.

In reality, collecting multi-kilogram samples from every storage site would be not only logistically unfeasible but also complicated by the difficulty of obtaining permission from government or privately operated storage facilities, and even then, these rapidly mobile species might evade collection. The occurrence of numerous first records for India underscores not only the richness of this fauna but also the likelihood that the mobility and patchy distribution of these mites have previously prevented their detection by taxonomists. This factor may partly explain the scarcity of previous taxonomic or faunistic studies on predatory mites in stored products in Kerala, leaving a significant knowledge gap.

The development and application of advanced sampling methodologies, such as continuous trapping systems capable of covering greater portions of storage facilities could reveal a more accurate picture of the predatory mite community. Such approaches should form a priority for future research, as they may uncover a much broader species pool and clarify the ecological role of these predators in stored-product pest management. The current study, therefore, not only provides a valuable baseline for the presence of predatory mites in North Kerala but also highlights methodological limitations and the need for innovation in sampling strategies to fully characterise this important but underexplored group.

5.2. Part II- Biology

Numerous studies have been conducted worldwide to explore the breeding and feeding biology of *Cheyletus malaccensis*. Nevertheless, the present study offers several novel and significant contributions. Especially, the use of *Suidasia nesbitti* as the prey mite; this approach has not been seen in previous studies, which commonly used *Acarus siro* and *Tyrophagus putrescentiae*. In addition, a specially designed 3D-printed, modified Petri dish was developed for the present breeding and feeding biology study. This innovative setup allowed for hassle-free experimentation and efficient predator management. The contrasting black colour of the Petri dish significantly improved the visibility of the prey mites.

The rearing conditions also add significant novelty to this work. A total of three different temperatures and three distinct humidity levels were tested. These temperature and humidity combinations were carefully selected to minimize overlap with previous studies. Under these previously unexplored conditions, the present study revealed distinct differences compared to earlier work conducted under near temperature and humidity ranges, thereby contributing to and expanding the existing knowledge on the developmental performance of *C. malaccensis* across a broader spectrum of temperature and humidity levels.

The numerous studies on *C. malaccensis* around the world can be attributed to its high predatory efficiency, robust body structure, widespread occurrence in stored products, and adaptability to diverse environmental conditions. Therefore, understanding its biology and developing effective mass-rearing methods are crucial steps toward its commercialization for biological control programs. While many studies have tested its predatory efficiency in various warehouse environments, no commercially available product has been developed or released (Arco et al., 2024). The mass-rearing results from the present study could serve as a strong foundation for the future development and commercialization of this predatory mite.

From a detailed study of published research articles worldwide, it has been found that even a slight change of 1°C and 5% RH, as well as the prey species causes a significant difference in the developmental duration of *C. malaccensis*. Although the present study largely avoided overlaps with the temperature and humidity conditions and prey preference observed in previous works by other researchers, a comparison between their results and those of this work, despite slight differences in conditions, may still be acceptable. However, such a comparison discussed here was interpreted with caution, as even this minor variation can lead to significant developmental biology differences. Moreover, the novel selection of *S. nesbitti* as prey is expected to result in significant differences in the developmental biology of predator. Given the absence of prior research investigating this specific prey-predator combination, a direct comparison may not be appropriate; nevertheless, a detailed discussion was included.

When examining the pre-oviposition period of *Cheyletus malaccensis*, Palyvos and Emmanouel (2011) recorded durations of 4.4 ± 0.1, 2.4 ± 0.1, and 1.4 ± 0.1 days at 25, 30, and 32.5°C, respectively. Interestingly, the present study revealed an opposite trend in the pre-oviposition period compared to their findings. At 25°C and 80% RH, Palyvos and Emmanouel reported a longer pre-oviposition period (4.4 ± 0.1 days) but a shorter oviposition duration (17.5 ± 0.5 days), whereas the present study observed a shorter pre-oviposition period (2.40 ± 0.17 days) alongside a significantly longer oviposition period (27.20 ± 0.47 days). This suggests that the conditions in the present study favored a reduced pre-oviposition phase and an extended oviposition period, which is highly advantageous for mass rearing programs. A shorter pre-oviposition period allows for faster population buildup, while a prolonged oviposition phase enhances reproductive output. This discrepancy may be attributed to differences in prey nutritional quality. As the present study used *S. nesbitti*, which may provide essential nutrients that enhance physiological functions related to egg production during the pre-oviposition phase, compared to *T. putrescentiae* in Palyvos and Emmanouel's study. Previous studies discussed in this section also support the observation that *T. putrescentiae* as prey leads to reduced fecundity, further reinforcing the role of dietary quality in reproductive performance.

Palyvos and Emmanouel (2011) reported a decreasing trend in the oviposition period of *C. malaccensis* with increasing temperature, and a similar pattern was observed in the present study. At 25 °C and 80% RH, the oviposition period was 27.20 ± 0.48 days, decreasing to 18.30 ± 0.21 days at 29 °C and 18.90 ± 0.44 days at 33 °C. These values are noticeably longer than those recorded by Palyvos and Emmanouel (2011), who reported 17.5 ± 0.5, 16.8 ± 0.5, and 15.4 ± 0.4 days at 25, 30, and 32.5 °C, respectively. The consistently longer oviposition periods observed in the present study contributed to the higher fecundity recorded. This difference may be attributed to the use of *S. nesbitti* as prey and the unique characteristics of the North Kerala biotype of *C. malaccensis*, potentially enhancing reproductive output under the tested conditions.

Al-Shammery (2014) investigated the developmental biology and life table parameters of *C. malaccensis* under conditions of 26°C and 65% relative humidity, using three different prey species viz., *Tyrophagus putrescentiae*, *Caloglyphus rodriguezi*, and *Acarus siro*. While the temperature and humidity conditions in the present study (25°C and 70±5% RH) are somewhat comparable, the 1°C temperature difference and 5% RH variation may still have substantial biological implications. Thus, any comparisons between the two studies must be made cautiously, as even minor temperature and humidity variations can significantly influence developmental outcomes.

The oviposition period in the present study differed markedly from those reported by Al-Shammery (2014), who documented shorter oviposition periods of 18.45 ± 1.82 days on a *T. putrescentiae* diet and 16.21 ± 1.48 days on an *A. siro* diet, whereas the present study observed a significantly longer oviposition period of 36 ± 1.14 days. Differences were also noted in pre-oviposition and post-oviposition durations. Al-Shammery (2014) reported pre-oviposition periods of 6.44±0.68 days (*T. putrescentiae* diet) and 8.78±0.82 days (*A. siro* diet), compared to only 3.10±0.05 days in the present study. Interestingly, post-oviposition periods were similar between the two studies: 3.55±0.42 days (*T. putrescentiae* diet) in Al-Shammery's work versus 3.50±0.10 days (*S. nesbitti* diet) in the present study.

Saleh et al. (1986) examined the developmental biology of *Cheyletus malaccensis* under controlled laboratory conditions (28 ± 1°C and 75 ± 5% RH), which focused on the influence of mating status. In contrast, the present study concentrated solely on copulated females and sexually produced males, allowing for a more targeted comparison of developmental parameters under comparable temperature conditions (29 ± 1°C and 80% RH). Despite slight variations in humidity, both studies provide important data on fecundity, developmental timing, and adult longevity. Both studies observed that copulation shortens the pre-oviposition period, with nearly identical values (2.6 ± 0.2 days in Saleh et al. vs. 2.76 ± 0.03 days in the present study). However, the oviposition period was notably longer in the present study (18.30 ± 0.20 days vs. 10.1 ± 0.3 days). Conversely, the post-oviposition period was slightly reduced in the present study (3.40 ± 0.06 days vs. 4.9 ± 0.3 days). Adult longevity also exhibited significant variation, with copulated females in the present study living considerably longer (24.46 ± 0.28 days) than those in Saleh et al.'s work (17.6 ± 0.3 days). The extended longevity likely contributed to the higher fecundity observed, as females had more time to deposit eggs.

Regarding fecundity, the present study observed a similar overall egg production at 25°C and 80% RH (227.40 ± 4.72 eggs/female) compared to the mean reported by Mukherjee (2012) (223.46 eggs/female at 25°C and 85% RH). However, at the higher temperature regime, the fecundity in the present study (139.90 ± 2.83 eggs/female at 29°C and 80% RH) was notably lower than the mean reported by Mukherjee (2012) (225.11 eggs/female at 30°C and 85% RH). This significant difference in fecundity may be attributed to genetic and biotypic variability among mite populations from different regions used in each study, which might have influenced their reproductive capacity (Palyvos and Emmanouel 2004).

Nangia and ChannaBasavanna (1990) reported a significantly lower fecundity of 37 ± 0.2 eggs per female at 24 °C and 80% RH when using *Tyrophagus putrescentiae* as prey, compared to the much higher fecundity of 227.40 ± 4.72 eggs per female observed in the present study at 25 °C and 80% RH with *Suidasia nesbitti* as prey, clearly demonstrating that prey diet markedly influences fecundity.

Reproductive output in the present study exhibited variations compared to that reported by Granich et al. (2016): *C. malaccensis* fed *M. ginglymura* exhibited the highest fecundity (310.7 ± 45.8 eggs/female), whereas those fed *S. nesbitti* showed intermediate fecundity (227.40 ± 4.72 eggs/female), still surpassing the reproductive output on *T. putrescentiae* (32.7 ± 4.5 eggs/female). The oviposition period for *C. malaccensis* on *S. nesbitti* (27.20 ± 0.47 days) was shorter than on *M. ginglymura* (53.0 ± 6.3 days) but longer than on *T. putrescentiae* (12.6 ± 1.9 days). Longevity followed a similar trend: females fed *S. nesbitti* lived 32.60 ± 0.43 days, and males 26.80 ± 0.30 days. These durations were lower than on *M. ginglymura* but higher than on *T. putrescentiae*.

Toldi et al. (2017) reported a peak fecundity of 415.62 ± 24.78 eggs/female for *C. malaccensis* when fed on *Dermanyssus gallinae* at 25°C and 80% RH. This was significantly higher than the 227.40 ± 4.72 eggs/female observed in the present study for *C. malaccensis* fed on *S. nesbitti* under identical temperature and humidity conditions. This marked difference highlights the influence of prey species on reproductive output, indicating variations in nutritional quality among different prey. Despite these differences in fecundity, survival rates at 25°C and 80% RH showed comparability between the studies, with Toldi et al. (2017) observing 70% survival to adulthood, which aligns closely with the 69.4 ± 0.93% survival rate recorded in the present study. This consistency indicates that temperature effects on predator survival may be relatively consistent regardless of the specific prey utilized.

For female reproductive performance, Liu et al. observed the highest total fecundity of 493.0 ± 104.52 eggs per female at 85% RH, accompanied by an oviposition period of 46.2 ± 8.21 days and a daily fecundity of 10.3 ± 1.20 eggs/day. When comparing these results with nearly similar conditions from the present study (i.e., 25°C and 80% RH), the fecundity was 227.40 ± 4.72, with an oviposition period of 27.20 ± 0.47 days and a daily fecundity of 8.57 ± 0.24 eggs/day. However, the highest fecundity from the present study was recorded at 25°C and 70% RH, with 292.60 ± 8.69 eggs/female. At a similar temperature and humidity level (24°C and 65% RH), Liu et al. (2018) reported their lowest fecundity of 418.0 ± 91.90 eggs per female. This observation contradicts the trend of decreasing fecundity with increasing humidity levels observed at 25°C in the present study.

When examining the fecundity data from Elhalawany et al. (2022), they recorded their highest fecundity rate (196 eggs per female) when *C. malaccensis* was fed on *A. siro* at 27°C and 80% RH. Although the present study did not test this exact temperature, the results at 25°C (80% RH) showed a higher fecundity of 227.40 ± 4.7 eggs per female, while at 29°C (80% RH), fecundity decreased to 139.90 ± 2.83 eggs per female. This suggests that increasing temperature reduces fecundity. The value of 196 eggs at 27°C, derived from the results of Elhalawany et al. falls logically between the present study's values of 227.40 ± 4.72 eggs at 25°C and 139.90± 2.83 eggs at 29°C. However, a clear contradiction arises when considering Elhalawany et al.'s reported lowest fecundity of 69.10 eggs per female at 22 °C and 80% RH with *Caloglyphus berlesei* as prey. Typically, lower temperatures are associated with prolonged developmental time and higher fecundity, but in this case, *C. berlesei* appears to offer poor reproductive potential despite the extended life cycle. This contrasts with *A. siro*, which yielded higher fecundity under similar conditions.

When comparing fecundity, Palyvos and Emmanouel (2011) recorded 88.6 ± 10.1 eggs per fertilized female at 25°C and 80% RH (in their study, they compared the reproductive output between fertilized and virgin females, as adult female *Cheyletus malaccensis* typically reproduce parthenogenetically.). In contrast, the present study reported a significantly higher fecundity of 227.40 ± 4.72 eggs per female under the same conditions. At 30°C, Palyvos and Emmanouel (2011) observed a fecundity of 169.7 ± 6.6 eggs per female, whereas the present study recorded 139.90 ± 2.83 eggs per female at 29°C and 80% RH. At 32.5°C and 80% RH, Palyvos and Emmanouel (2011) reported 107.8 ± 4 eggs, while the present study observed 120 ± 3.4 eggs at 33°C. These findings suggest that the optimal temperature for maximum fecundity in the present study was 25°C and 80% RH, whereas Palyvos and Emmanouel (2011) identified 30°C as optimal. However, their study did not achieve higher fecundity at any temperature compared to the present results, indicating that biotype differences and prey nutritional quality may play a significant role in fecundity, potentially outweighing the strong influence of temperature.

Saleh et al. (1986) examined the developmental biology of *Cheyletus malaccensis* under laboratory conditions of 28 ± 1 °C and 75 ± 5% relative humidity. One of the most striking differences between their results and the present study lies in fecundity, with the current work recording a substantially higher egg production (139.90 ± 2.83 eggs/female) compared to Saleh et al.'s findings (50.6 ± 1.2 eggs/female). This disparity is likely attributable to differences in prey species, as Saleh et al. used *Aleuroglyphus ovatus*.

While Al-Shammery's (2014) work indicated a longer lifespan for *C. malaccensis*, this did not correlate with higher fecundity. In fact, their study reported the lowest fecundity among all existing studies on this species. When fed on *T. putrescentiae*, *C. malaccensis* produced 41.33 ± 4.22 eggs per female with a daily fecundity rate of 2.24, while diets of *Caloglyphus rodriguezi* and *Acarus siro* yielded even lower outputs, which was 28.22±0.78 eggs per female (1.68±0.78 eggs/day) and 20.08±2.08 eggs per female (1.24±0.64 eggs/day), respectively (at 26°C/ 65% RH). These values were substantially lower than those observed in the present study, which recorded a significantly higher fecundity of 292.60 ± 2.75eggs per female and a daily egg-laying rate of 8.18±0.77 at 25°C and 70±5% RH.

Collectively, Al-Shammery's findings deviated markedly from other studies in terms of fecundity, developmental duration, and doubling time. Although the temperature used in their study (26°C) falls within the generally accepted optimal range for *C. malaccensis*, the substantially lower fecundity observed is unexpected. Possible explanations include biotypic variation or the relatively low humidity level (65% RH), which may be less favourable for development. Differences in experimental design may also have contributed. Typically, such low reproductive outputs are seen only under extreme thermal conditions. For example, Palyvos and Emmanouel (2011) recorded reduced fecundity (25.2 ± 1.3 eggs per female at 17.5°C, 80% RH; 55.5 ± 2.7 eggs per female at 35°C, 80% RH) when *C. malaccensis* was fed *T. putrescentiae*. In contrast, when comparing the fecundity rates reported by Al-Shammery (2014), the present study's use of *S. nesbitti* as prey yielded markedly higher reproductive performance (292.60 ± 2.75 eggs/female at 25 °C and 70% RH). Compared with those findings, the present results reaffirm its value as a superior prey species that supports both rapid development and maximal fecundity. *S. nesbitti* clearly outperformed *Caloglyphus rodriguezi*, *Acarus siro* and *Tyrophagus putrescentiae* which in Al-Shammery's work produced only 28.22 ± 0.78, 20.08 ± 2.08 and 41.33 ± 4.22 eggs/female, respectively.

However, the findings of Al-Shammery (2014) strongly contradicted those of Sun et al. (2020), who reported that *C. malaccensis* fed on *Acarus siro* exhibited higher fecundity (even higher than when fed on *Suidasia nesbitti*, but a lower net reproductive rate relative to total fecundity than on *S. nesbitti*). This was further supported by Sun et al. (2020) through their evaluation of the life table parameters of *C. malaccensis* at 22, 24, 28, 30, and 32 °C under a constant relative humidity of 75%. A direct comparison was challenging, as the temperature, humidity, and prey species conditions in Sun et al. (2020) were not closely similar to those in the present study. However, a comparison was made between the 25, 29, and 33°C with 70% RH conditions in the present study and the 24, 28, and 32°C with 75% RH conditions of Sun et al. which revealed some similarities and differences.

Notable differences were observed at conditions near 24-25°C and 70-75% RH. Sun et al. (2020), at 24°C and 75% RH, reported a generation time of 30.30 ± 1.97 days, a net reproductive rate (R_0) of 204.75 ± 60.33, an intrinsic rate of increase (r_m) of 0.18 ± 0.02, a finite rate of increase (λ) of 1.19 ± 0.02, a total fecundity of 526.15 ± 6.85 eggs, and a female lifespan of 59.51 ± 4.48 days. Comparatively, the present study, at 25°C and 70% RH, found a shorter generation time of 20.22 ± 0.38 days, a reduced R_0 of 108.10 ± 1.84, a higher r_m of 0.232 ± 0.004, a higher λ of 1.26 ± 0.005, a significantly lower total fecundity of 292.60 ± 2.75 eggs, and a similar female lifespan of 59.72 ± 1.46 days.

Further disparities emerged under conditions of 28-29°C and 70-75% RH. Sun et al. (2020), at 28°C and 75% RH, reported a generation time of 24.51 ± 0.66 days, an R_0 of 290.25 ± 70.58, an r_m of 0.23 ± 0.15, a λ of 1.26 ± 0.19, a total fecundity of 544.52 ± 13.47 eggs, and a female lifespan of 56.91 ± 6.68 days. In contrast, the present study, at 29°C and 70% RH, found a shorter generation time of 14.05 ± 0.14 days, a notably lower R_0 of 49.80 ± 0.98, a higher r_m of 0.278 ± 0.003, a higher λ of 1.32 ± 0.005, a considerably lower total fecundity of 127.00 ± 2.63 eggs, and a substantially shorter female lifespan of 34.12 ± 0.199 days.

Finally, at temperatures near 32-33°C and 70-75% RH, the trends largely converged in some aspects. Sun et al. (2020), at 32°C and 75% RH, reported a generation time of 12.49 ± 0.65 days, an R_0 of 67.03 ± 18.02, an r_m of 0.33 ± 0.03, a λ of 1.40 ± 0.04, a total fecundity of

148.96 ± 16.10 eggs, and a female lifespan of 22.15 ± 1.22 days. The present study, at 33°C and 70% RH, showed a comparable generation time of 13.38 ± 1.10 days, a lower R_0 of 59.2 ± 15.3, a slightly lower r_m of 0.30 ± 0.03, a slightly lower λ of 1.35 ± 0.05, a lower total fecundity of 111.0 ± 12.4 eggs, and a longer female lifespan of 32.08 ± 2.48 days.

Across both studies, it is generally consistent that increasing temperature leads to a decrease in the generation time and the lifespan of *C. malaccensis*. However, a significant divergence is observed in the trend of fecundity with increasing temperature. In the present study, increasing temperature consistently reduced fecundity. Conversely, Sun et al. (2020) reported an increase in fecundity from 24°C/ 75% RH (526.15 ± 6.85 eggs) to 28°C (544.52 ± 13.47 eggs), suggesting an optimal temperature for fecundity around 28°C with 75% RH for their experimental setup. This contrasts with the findings of present study, which suggest 25°C with 70% RH as optimal for maximum fecundity. These differences indicates that small changes in temperature and humidity conditions across studies can have significant effects on biological parameters. The markedly higher fecundity rates reported by Sun et al. (2020) (544.52 ± 13.47 eggs) and Liu et al. (2018) (418.0 ± 91.90 eggs per female), both employing *Acarus siro* as prey, compared to the maximum fecundity of 292.60 ± 2.75 eggs per female recorded in the present study (using *S. nesbitti*), strongly suggest that *A. siro* provides a more nutritionally superior diet for *C. malaccensis*, leading to greater reproductive output.

Despite the lower total fecundity, *S. nesbitti* appears to offer compensatory benefits in terms of reproductive efficiency and adaptability to warmer conditions. The shorter generation time (20.22 ± 0.38 days at 25°C/70% RH versus 30.30 ± 1.97 days on *A. siro* at 24°C/75% RH) further supports its suitability in environments where rapid population turnover is preferred. Thus, while *A. siro* maximizes egg production, *S. nesbitti* provides a more balanced life-history trade-off, making it a viable alternative under specific ecological or experimental conditions.

The findings from the present study exhibit notable differences when compared to similar work by Nangia and ChannaBasavanna (1990), probably due to variations in experimental conditions and prey species (*Tyrophagus putrescentiae*) used. Their study observed a longer incubation period (6 ± 0.05 days at 24°C and 80% RH), while also recording shorter larval (3 ± 0.5 days) and protonymphal (4 ± 0.5 days) durations, whereas, the present study recorded a shorter incubation period (3.90 ± 0.24 days at 25°C and 80% RH), extended larval (6.80 ± 0.21 days) and protonymphal (6.150 ± 0.20 days) stages.

Mukherjee (2012), in her doctoral thesis, investigated the breeding biology of *Cheyletus malaccensis* across two distinct temperature regimes (25°C and 30°C) with a fixed relative humidity of 85% and *Tyrophagus putrescentiae* as prey species. Comparison of present results with their work revealed notable differences. In terms of developmental time, incubation periods were generally shorter in the present study (3.90 ± 0.24 days at 25°C and 80% RH and 2.12 ± 0.03 days at 29°C and 80% RH) compared to Mukherjee (2012) (4.7 ± 0.2 days at 25°C and 85% RH and 2.76 ± 0.1 days at 30°C and 85% RH). Similarly, larval, protonymph, and deutonymph durations were consistently reduced in the current research. This accelerated development resulted in a shorter egg-to-adult period in the present study (e.g., 22.60 ± 0.59 days for females at 25°C vs. 24.6 ± 0.5 days in Mukherjee, 2012). These differences could be attributed to the prey species utilized. The present study employed *S. nesbitti* as prey, whereas Mukherjee (2012) used *T. putrescentiae*. Differences in the nutritional quality or accessibility of these distinct prey species could influence the developmental rates of the predator.

Nangia and ChannaBasavanna reported higher male longevity (42 ± 0.5 days at 24°C/ 80% RH) compared to females (37 ± 0.56 days), but, the results from the present study indicated the opposite trend, with females (32.60 ± 0.43 days at 25°C/ 80% RH) outliving males (26.80 ± 0.30 days). However, both studies documented a near 1:1 sex ratio, suggesting that the observed differences may be due to genetic variability within the mite populations or experimental design, potentially involving controlled mating with female and diploid males (homomorphic males), similar to the approach in the present study, even if not explicitly mentioned in their publication.

Longevity of *C. malaccensis* females was comparable or slightly higher in the present study at 25°C/ 80% RH (32.60 ± 0.43 days) than in Mukherjee (2012) (29.5 ± 0.3 days at 25°C/ 80%). The sex ratio exhibited a pronounced difference as the present study reported an almost equal ratio (1:1) in 25°C and 29°C, sharply contrasting with the ratios with a female bias (6.6:1 at 25°C; 4.5:1 at 30°C) observed by Mukherjee (2012). However, the findings from both studies aligned with the fact that higher temperatures accelerate mite development time.

The developmental parameters observed in the present study, using *Suidasia nesbitti* as the sole prey for *C. malaccensis* differed notably from those reported by Granich et al. (2016), who used *Megninia ginglymura* and *Tyrophagus putrescentiae* as two different prey sources for the same predator. While Granich et al. (2016) maintained conditions at 25 ± 1°C, 80 ± 5% RH, and a 12-hour photoperiod, the present study employed the same temperature and humidity but with a continuous 24-hour photoperiod. However, the isolated effect of photoperiod cannot be determined due to the inherent differences in prey species between the two studies. The egg-to-adult period of *C. malaccensis* reared on *S. nesbitti* (22.60 ± 0.59 days) was shorter than when fed *M. ginglymura* (25.0 ± 0.4 days) but comparable to development on *T. putrescentiae* (20.9 ± 0.5 days). Survivorship, however, was markedly lower (69.4 ± 0.93 %) than the near-complete survival (96.6%) reported by Granich et al. (2016), suggesting differences in prey suitability or other unaccounted stressors.

Life table parameters further highlighted these differences, with *S. nesbitti* showing a lower net reproductive rate (R_0 = 86.60 ± 3.49) than *M. ginglymura* (135.6), but higher than *T. putrescentiae* (13.9), as reported in Granich et al. (2016). Furthermore, *S. nesbitti* also led to a significantly shorter doubling time (3.90 ± 0.12 days) compared to *M. ginglymura* (5.8 days) and *T. putrescentiae* (7.9 days), indicating faster population growth. These differences highlight the critical role of prey-specific adaptations in shaping the life-history traits of *C. malaccensis*, thus necessitating further studies to isolate the effects of diet versus environmental variables.

Toldi et al. recorded *C. malaccensis* with a net reproductive rate (R_0) of 42.71 ± 2.54, an innate capacity for increase (r_m) of 0.19 ± 0.03, a finite rate of increase (λ) of 1.21 ± 0.00, and a doubling time (DT) of 3.69 ± 0.06 days when fed on *D. gallinae* at 25°C. In contrast, the present study, under similar conditions (25°C, 80% RH) but with *S. nesbitti* as prey, recorded an even higher net reproductive rate (R_0 = 86.60 ± 3.49) and a closer innate capacity for increase (r_m = 0.180 ± 0.006), along with a significantly shorter mean generation time (T = 25.00 ± 0.69 days) and a slightly higher doubling time (DT = 3.90 ± 0.12 days) and a near similar finite rate of increase (1.20 ± 0.007) relative to *D. gallinae* in Toldi et al.'s study. These comparative differences suggest that *S. nesbitti* may be a more favorable prey for *C. malaccensis* than *D. gallinae*, in terms of higher reproductive output.

A comparison with the findings of Liu et al. (2018), who investigated the developmental biology of *C. malaccensis* using *Acarus siro* as prey species, reveals notable differences from the present study. However, a direct comparison cannot be made due to non-overlapping experimental conditions, as Liu et al. maintained a constant temperature of 24°C at 65%, 85%, and 95% RH, whereas the present study included conditions of 25°C with 70%, 80%, and 90% RH.

Regarding the developmental time from egg to adult, Liu et al. (2018) reported the longest duration for females at 65% RH (18.6 ± 0.48 days) and shortest (16.3 ± 1.27 days) at

85% RH. In the present study, at a comparable temperature of 25°C, the female egg-to-adult duration was observed to be 17.12 ± 0.33 days at 70% RH and 22.60 ± 0.59 days at 80% RH. This finding contradicted the trend reported by Liu et al., which suggested that increasing humidity at same temperature level reduces development time for females. For males, Liu et al. found the shortest developmental time at 95% RH (12.6 ± 0.48 days) and the longest at 65% RH (14.7 ± 0.69 days). The present study recorded male developmental durations of 10.20 ± 0.16 days at 25°C and 90% RH, and 12.10 ± 0.27 days at 25°C and 70% RH. These differences in developmental durations suggest that *S. nesbitti* may support slightly faster development for males, particularly at higher humidities when compared to *A. siro*. Despite these numerical variations, a consistent trend of decreasing male developmental duration with increasing humidity levels was observed in both studies, highlighting the importance of ambient moisture for *C. malaccensis* development regardless of the specific prey species.

Significant differences were also found in adult longevity and lifespan. Liu et al. (2018) reported a male adult longevity of 83.5 ± 7.53 days at 95% RH and a total lifespan (egg to death) of 95.8 ± 7.61 days. In contrast, the male adult longevity at 25°C and 90% RH in the present study was 21.30 ± 0.62 days, with a total male lifespan of 31.50 ± 0.63 days under these conditions. This substantial difference indicates a considerably longer lifespan for *Cheyletus malaccensis* when preying on *Acarus siro*.

In the study by Elhalawany et al. (2022), the developmental duration of *C. malaccensis* was examined using three different prey species, viz., *Acarus siro*, *Caloglyphus berlesei*, and *Tyrophagus putrescentiae*. Their experiments were conducted at temperatures of 22, 27, and 32 ± 2°C with a constant humidity level of 80 ± 5% RH. Due to differences in prey species and temperature conditions, a direct comparison with the present study was not entirely feasible. However, a partial comparison was made as both studies used the same humidity level (80 ± 5% RH). Nevertheless, an exact comparison accounting for temperature and prey species would not be scientifically precise. When comparing life cycle durations, Elhalawany et al. (2022) reported the shortest developmental period for *C. malaccensis* as 11.60 days for females and 8 days for males when fed on *A. siro* at 32°C and 80 ± 5% RH. Interestingly, the present study, conducted at a similar temperature (33 ± 1°C) and humidity (80 ± 5% RH), observed nearly identical developmental times when *C. malaccensis* was fed on *Suidasia nesbitti*, with 11.60 ± 0.36 days for females and 8.20 ± 0.32 days for males (with only a slight difference in male developmental time). However, since Elhalawany et al. did not include standard errors in their results, a more precise comparison is not possible.

On the other hand, the longest life cycle duration in the study of Elhalawany et al. was observed at 22 ± 2°C and 80 ± 5% RH, where females took 29.5 days and males 21.2 days to develop when fed on *C. berlesei*. In contrast, the present study at 25°C and 80% RH (the lowest temperature tested here) recorded 22.60 ± 0.59 days for females and 16.80 ± 0.39 days for males. However, this comparison is not entirely appropriate due to the 3°C temperature difference, which significantly influences developmental rates. Regarding longevity, Elhalawany et al. (2022) noted that *A. siro* diet at 22°C and 80% RH resulted in the longest female longevity (43.6 days), whereas in the present study, *S. nesbitti* diet at 25°C yielded a female longevity of 32.60 ± 0.43 days. Conversely, Elhalawany et al. observed the shortest female longevity of 20.65 days at 32 ± 2°C and 80 ± 5% RH when fed on *T. putrescentiae*. In comparison, the present study recorded a female developmental time of 23.80 ± 0.54 days at 33± 1°C and 80% RH. Notably, the shortest female longevity in the present study was 15.20 ± 0.41 days at 33°C and 90% RH. This suggests that, while higher temperatures generally reduce longevity, a diet of *S. nesbitti*, combined with high humidity levels (e.g., 90% RH), leads to a further shortened female longevity compared to *T. putrescentiae* diet at these elevated temperatures.

When comparing the doubling times between these two studies, consistent trends emerge. Elhalawany et al. reported a doubling time of 3.20 days at 27°C and 80% RH using an *A. siro* diet. In the present study, a comparable doubling time of 3.90 ± 0.12 days was recorded at 25°C and 80% RH. At 29°C and 80% RH, the present study observed a shorter doubling time of 2.77 ± 0.02 days. Elhalawany et al. also documented a doubling time of 2.97 days at 32 °C and 80% RH on an *A. siro* diet. In contrast, the present study recorded an even lower doubling time of 2.51 ± 0.09 days at 33°C and 80% RH. Notably, when Elhalawany et al. fed *C. malaccensis* with *T. putrescentiae* at 32°C, the doubling time increased to 3.57 days, compared to 2.97 days on the *A. siro* diet at the same temperature (32°C). This highlights the significant influence of prey species on population growth rates. Given these results, *S. nesbitti* demonstrates a considerably shorter doubling time (2.51 ± 0.09 days) at high temperatures (32–33°C), making it a more efficient option for achieving rapid population growth under such conditions.

Apart from these findings, Elhalawany et al. (2022) and Yousef et al. (1982) reported in their results that *C. malaccensis* prefers the immature stages of prey mites, regardless of species. This finding is consistent with the feeding biology results in the present study.

Palyvos and Emmanouel (2009) evaluated the temperature-dependent development of *Cheyletus malaccensis* under six temperature conditions (17.5, 20, 25, 30, 32.5, and 35°C) at a constant humidity level of 80 ± 5% RH. The temperature of 25°C and 80% RH in their study matched exactly with the present study, while their temperatures of 30°C and 32.5°C closely aligned with the 29°C and 33°C conditions used here. However, since the present study employed a different prey species (*Suidasia nesbitti* vs. *Tyrophagus putrescentiae* in Palyvos and Emmanouel, 2009), a direct comparison is not feasible. Moreover, in contrast to the study by Palyvos and Emmanouel which maintained a constant humidity level, the present investigation explored the effects of varying humidity levels under different temperature conditions.

According to Palyvos and Emmanouel (2009), the developmental time of *C. malaccensis* decreased with increasing temperature, and this finding is consistent with the present study. Specifically, under the identical condition of 25°C and 80% RH, the larval developmental duration was 7.5 ± 0.2 days in Palyvos and Emmanouel's study compared to 6.80 ± 0.21 days in the present study. Similarly, at 32.5°C and 80% RH (Palyvos and Emmanouel, 2009) versus 33°C and 80% RH (present study), the larval durations were 4.3 ± 0.2 days and 3.4 ± 0.16 days, respectively. These differences, despite matching temperature and humidity conditions, are likely due to variations in the nutritional quality of the prey, suggesting that prey species significantly influence the developmental rates. Furthermore, when comparing protonymphal and deutonymphal developmental durations, the present study recorded shorter durations than those reported by Palyvos and Emmanouel (2009). Biotypic variations between populations and differing experimental conditions may also contribute to these discrepancies. Nevertheless, the findings suggest that *S. nesbitti* as a prey species plays a crucial role in reducing the developmental duration of *Cheyletus malaccensis* compared to *T. putrescentiae*.

Following the work of Palyvos and Emmanouel (2009), the authors extended their research by incorporating additional developmental parameters of *C. malaccensis* using the same prey species (*T. putrescentiae*) under identical temperature and humidity conditions (17.5, 20, 25, 30, 32.5, and 35 ± 1°C, and 80 ± 5% RH). Similar to their previous study, one temperature-humidity condition (25°C, 80% RH) matched exactly with the present study, while two others were nearly matched (29°C vs. 30°C; 33°C vs. 32.5°C).

Regarding survival rates, Palyvos and Emmanouel (2011) reported a higher survival rate at 25°C/ 80% RH (79%) compared to the present study (69.4 ± 0.93%). However, even at their reported optimal fecundity temperature (30°C), their survival rate (71%) was lower than that observed in the present study at 29°C (78.2 ± 0.27%). At 32.5°C, Palyvos and Emmanouel (2011) recorded a survival rate of 73.7%, whereas the present study showed a decline to 59.7 ± 1.6% at 33°C. Notably, it is unusual for *C. malaccensis* to exhibit a higher survival rate at 32.5°C (73.7%) than at 25°C, as elevated temperatures typically reduce developmental time, fecundity, and survival rates. This discrepancy raises questions about the underlying factors influencing survival under high-temperature conditions.

Regarding female longevity, Palyvos and Emmanouel (2011) recorded days of 27.4 ± 2.0 days at 25°C/80% RH, 26.8 ± 0.9 days at 30°C, and 22.3 ± 0.8 days at 32.5°C. In comparison, the present study observed 32.60 ± 0.43 days at 25°C/80% RH, 24.46 ± 0.28 days at 29°C, and 23.80 ± 0.54 days at 33°C. Here, both studies consistently demonstrated that increasing temperatures reduce longevity.

When examining life table parameters, both studies showed that the intrinsic rate of increase (r_m) increased with temperature. Palyvos and Emmanouel (2011) recorded r_m values of 0.115 at 25 °C (80% RH), 0.183 at 30 °C, and 0.213 at 32.5 °C, while the present study observed higher values: 0.180 ± 0.006 at 25 °C, 0.251 ± 0.002 at 29 °C, and 0.280 ± 0.010 at 33 °C (all at 80% RH). This supports the conclusion that rising temperatures accelerate population growth rates in *C. malaccensis*. However, the net reproductive rate (R_0) exhibited contrasting trends between the two studies. In Palyvos and Emmanouel's work, R_0 followed a non-linear pattern, with the highest value at 30 °C (122.18), a lower value at 25 °C (70.07), and an intermediate value at 32.5 °C (79.49). In contrast, the present study showed a consistent decline in R_0 with increasing temperature: 86.60 ± 3.49 at 25 °C, 55.40 ± 1.13 at 29 °C, and 42.70 ± 2.21 at 33 °C (all at 80% RH). Although the present study demonstrated overall lower R_0 values compared to Palyvos and Emmanouel, this may reflect differences in prey species, strain adaptability, or experimental design.

Both studies consistently demonstrated that as temperature increased, the doubling time (DT) of *C. malaccensis* decreased. Palyvos and Emmanouel (2011) reported doubling times of 6.04 days at 25 °C, 3.79 days at 30 °C, and 3.25 days at 32.5 °C. In contrast, the present study recorded significantly shorter doubling times: 3.90 ± 0.12 days at 25 °C, 2.77 ± 0.02 days at 29 °C, and 2.51 ± 0.09 days at 33 °C (all at 80% RH). Similarly, the finite rate of increase (λ) in Palyvos and Emmanouel's study was 1.12 (25 °C), 1.20 (30 °C), and 1.24 (32.5 °C), whereas the present study reported higher values: 1.20 ± 0.007, 1.28 ± 0.002, and 1.32 ± 0.014, respectively.

Palyvos and Emmanouel's data also showed that extreme temperatures (17.5 °C and 35 °C) resulted in much longer doubling times (21.13 and 4.67 days, respectively), indicating developmental stress beyond optimal thresholds. The temperature range tested in the present study (25–33 °C) appears to fall within the optimal developmental window for *C. malaccensis* under the given conditions.

The present work aligns with some of the previously discussed studies in terms of expected biological parameters such as fecundity, generation time, lifespan, and doubling time of *C. malaccensis*. However, notable differences were observed when comparing the results with those of Al-Shammery (2014), where many key parameters differed significantly.

A key difference was observed in the developmental duration of female *C. malaccensis* between the present study and that reported by Al-Shammery (2014). Al-Shammery (2014) recorded development durations (egg to adult) of 26.12 ± 3.4 days on a *T. putrescentiae* diet, 29.61 ± 3.88 days when *Acarus siro* offered as prey, and 28.24 ± 3.62 days when fed with *C rodriguezi* (at 26°C and 65% RH). In contrast, the present study recorded a much shorter egg-to-adult duration of only 17.12 ± 0.33 days (at 25°C and 70% RH).

Adult longevity was another parameter that exhibited significant variation. Al-Shammery (2014) recorded a much shorter adult longevity of 28.44 ± 2.80 days (on *T. putrescentiae* diet), whereas the present study observed a longer longevity of 42.60 ± 1.17 days (*S. nesbitti* diet). Despite the extended longevity in the present study, the total life cycle duration (egg to adult) was shorter (17.12 ± 0.33 days) compared to Al-Shammery's findings (26.12 ± 3.4 days on *T. putrescentiae*). This difference was mainly due to the fact that the developmental time of immature stages in Al-Shammery's study averaged 5-8 days, prolonging the egg-to-adult duration (e.g., 6.86 ± 0.78 days for female protonymph of *Cheyletus malaccensis* preyed on *T. putrescentiae*), whereas the present study recorded a shorter duration of 4.76 ± 0.11 days.

Despite the lower reproductive output, Al-Shammery's study reported higher survival rates (92% on a *T. putrescentiae* diet and 82% on an *A. siro* diet), possibly due to reduced population pressure or manageable clutch sizes. In contrast, the present study observed a survival rate of 70.0 ± 0.57 % under conditions of 25°C and 70±5% RH. Net reproductive rates also differed markedly between the studies. Al-Shammery's results showed rates of 26.47 (*T. putrescentiae*), 24.63 (*C. rodriguezi*), and 14.53 (*A. siro*), values that were nearly four times lower than the present study's rate of 108.10 ± 1.84. Similarly, doubling times in Al-Shammery's work were considerably longer, including 11.75 days (*T. putrescentiae*), 15.75 days (*C. rodriguezi*), and 21.66 days (*A. siro*), while the present study recorded just 2.99 ± 0.05 days.

Although numerous studies have investigated the developmental biology of *Cheyletus malaccensis*, research on its feeding biology and prey preferences remains relatively limited. Moreover, among the existing feeding biology studies, only a few are suitable for direct comparison with the present study. This is because many focus on different parameters, such as prey density or the intrinsic rate of population increase of various prey species. Therefore, only a limited number of studies were selected for comparison, as their methodologies and findings aligned closely with those of this study.

The feeding biology study by Zhu et al. (2019) focused exclusively on adult female *Cheyletus malaccensis* as predators, whereas the present study expanded the scope by including multiple developmental stages of the predator viz., larvae, protonymphs, deutonymphs, adult males, and adult females. This broader approach enabled a more comprehensive understanding of prey preferences across the predator's life cycle. However, direct comparisons between the two studies can only be made for the adult female stage of *C. malaccensis*.

In terms of prey selection, Zhu et al. (2019) tested *Aleuroglyphus ovatus* across different developmental stages (eggs, larvae, nymphs, males, and females). The present study used *Suidasia nesbitti* as prey, covering eggs, larvae, protonymphs, tritonymphs, adult males, and adult females. Unlike Zhu et al. (2019), who grouped nymphal stages collectively, the present study distinguished between immature stages, specifically protonymphs and tritonymphs enabling a more refined analysis of prey preferences in *C. malaccensis*. A key similarity between the two studies was the consistent preference for larvae as the most consumed prey stage. Zhu et al. (2019) reported that adult female *C. malaccensis* consumed larvae at the highest rate (13.2 ± 1.077), followed by nymphs (9.0 ± 0.894), while eggs (1.7 ± 0.458), males (2.7 ± 0.640), and females (0.8 ± 0.400) were consumed in much lower quantities, establishing a clear preference order: larva > nymph > male > egg > female.

The present study confirmed this general trend for larval preference, with adult females showing the highest consumption of larvae (13.2 ± 2.04), followed by protonymphs (9.5 ± 1.08) and tritonymphs (9.0 ± 1.33). For these stages, the consumption rates closely matched those reported by Zhu et al. (2019), despite the slightly higher standard deviations in the present work. However, notable deviations were observed in the consumption of adult male and female prey. Specifically, the consumption rate of adult males in the present study (3.60 ± 0.84) was distinctly higher than that reported by Zhu et al. (2.7 ± 0.64), and adult female prey were also consumed at a significantly higher rate (2.8 ± 0.75 vs. 0.8 ± 0.400). These differences suggest a broader or more flexible prey acceptance by *Cheyletus malaccensis* under the experimental conditions of the present study. Moreover, the consistency in high consumption rates of larval and nymphal prey, despite slightly higher standard deviations, may reflect the upper limit of its predation capacity.

However, the present study revealed additional nuances when examining other predator stages. Predatory larvae showed a preference for eggs (8.0 ± 1.05) and larvae (7.0 ± 1.25) but avoided adult prey. Protonymph predators displayed a strong preference for larvae (9.0 ± 1.15) and protonymph prey (6.5 ± 1.08). Deutonymph predators exhibited a similar trend, heavily consuming larvae (9.9 ± 1.29) and other nymphal stages. Interestingly, adult male predators consumed larvae (11.5 ± 1.51) and nymphs (9.0–9.2) at high rates but also showed a slightly higher consumption of adult prey compared to adult female predators, a distinction not observed in Zhu et al.'s study. Both studies agreed that eggs and adult prey were generally less preferred, with adult female prey being the least consumed.

The results from the present study provides critical short-term predation metrics for *C. malaccensis* preying on *S. nesbitti* under controlled conditions (29°C, 80% RH), revealing that adult females consume 13.2 larvae, 9.5 protonymphs, and 9.0 tritonymphs per 24-hour period, demonstrating their high efficacy against immature stages. These results align with and extend the findings of Pekár and Hubert (2008), who showed that *C. malaccensis* achieves long-term biocontrol of *Acarus siro* at lower temperatures (15-25°C), with 3-9 predators per 100 prey suppressing populations by 90% over 21 days. While Pekár and Hubert quantified population-level suppression, the high-resolution, stage-specific predation data from the present study offers immediate insights into predator-prey interactions under warmer storage conditions, where *C. malaccensis* exhibits even greater voracity. Together, these studies demonstrate the predator's adaptability across temperatures and prey species, with present work highlighting its potential for rapid control of *S. nesbitti* infestations in tropical storage environments. Future studies combining short-term predation rates with long-term population modelling could further optimize release ratios for field applications.

While the present study focused specifically on stage-specific, short-term predation by *C. malaccensis* on *S. nesbitti* under tropical storage conditions (29°C, 80% RH), earlier work by Cebolla et al. (2009) explored the broader prey range of the same predator across multiple mite and insect species at cooler conditions (25°C, 75% RH). Although their study differed in scope, emphasizing long-term (21-day) suppression across a wide array of prey types, it similarly affirmed the acarophagous tendency of *C. malaccensis,* with highest predation recorded on certain mite species and negligible effects on insect eggs. These differences in prey selection, assessment duration, and environmental conditions highlight the predator's context-dependent feeding behavior. While Cebolla et al. identified *A. ovatus* and *L. destructor* as particularly susceptible, the present findings on *S. nesbitti* add new prey-specific insights, especially under warmer conditions relevant to tropical storage environments. Together, these studies reinforce *C. malaccensis* as an effective predator of various acarid mites.

The mass-rearing system developed in the present study demonstrates the remarkable reproductive potential of *C. malaccensis* under tropical conditions (29°C, 80% RH), where an initial population of 400 predators explosively multiplied 36.5-fold to 14,650 individuals within just 30 days when provided weekly with 50,000-60,000 *S. nesbitti* prey. This dramatic population growth, far exceeding reported rates at lower temperatures, reveals the predator's exceptional adaptability to warm storage environments. Although numerous published studies have addressed the developmental biology, predatory efficiency, and functional responses of *Cheyletus malaccensis*, there is a notable lack of research specifically focused on its mass-rearing. In most existing studies, *C. malaccensis* has been reared only as part of experimental setups for developmental or behavioural assessments, without detailing dedicated mass-rearing protocols or systems. To date, there are no established experimental designs or published methodologies available for large-scale rearing of *C. malaccensis*. However, a related species within the same family viz., *Cheyletus eruditus*, was successfully mass-reared in a study by Žďárková (1986), providing a useful reference for comparing the mass-rearing strategies and outcomes presented in the current study.

Žďárková's (1986) mass rearing experiment on *C. eruditus* emphasized methodological minimalism, using paper bags containing 100g of lettuce seeds as a substrate, maintained at

25°C and 75% relative humidity (RH). This method relied on a single inoculation of prey (*Acarus siro*) at a predator-prey ratio of 1:100-200, yielding approximately 2,100 predators after 28-35 days with minimal intervention. The lettuce seeds proved ideal for *C. eruditus*, as they supported rapid predator multiplication while minimizing residual prey populations, enabling direct deployment in infested stores or cold storage (0°C) for up to 3 months. Whereas, *C. malaccensis* preferred to thrive on wheat substrates, particularly those with a broken texture, as this provided optimal support for egg laying and hiding. In comparison to the methodology used in Žďárková's study, the present work employed a more intensive rearing system, utilizing ventilated plastic containers with a wheat-based substrate and selecting *S. nesbitti* as the prey species. Rearing at 29°C and 80% RH under constant darkness accelerated development, achieving a 36.5-fold population increase (14,650 predators/container) within 30 days. The multiplication rate of *C. malaccensis* significantly exceeded that of *C. eruditus* under their respective optimal conditions. These interspecific differences are crucial considerations when designing mass-rearing protocols. However, extended rearing of *C. malaccensis* to 60 days led to a sharp decline (13.45-fold) due to waste accumulation and cannibalism, highlighting the need for timed harvests.

Environmental adaptability further distinguished the two methods. Žďárková's 25°C protocol suited temperate regions and integrated seamlessly with post-fumigation biocontrol, leveraging the predator's cold tolerance. The *C. malaccensis* system, optimized for 29°C and 80% RH, catered to tropical climates where such conditions are ambient, reducing energy costs. Both studies highlighted cannibalism as a limiting factor but addressed it through different strategies, with the rearing of *C. eruditus* managed via cold storage and that of *C. malaccensis* through timed harvests prior to population collapse.

The experimental regimes employed in the present study, designed to simulate the warm (25–33 °C) and humid (70–90% RH) microclimate of North Kerala, provide a model for the consistently challenging conditions of coastal and high-rainfall storage zones across tropical India. However, the climatic diversity of Indian warehouses requires a careful comparison. In the coastal and southern states (e.g., Kerala, Karnataka, Tamil Nadu, coastal Maharashtra, and West Bengal), conditions often align closely with those tested, with annual averages of 25–30 °C and 75–85% RH, making the findings of this study applicable. In contrast, warehouses in the northern and northwestern grain belts (e.g., Punjab, Haryana, Western Uttar Pradesh) experience a more continental climate, characterized by extreme seasonal variation: summer highs can exceed 40 °C while winter temperatures frequently drop below 15 °C, coupled with low relative humidity (often 40–60% for much of the year). Similarly, the semi-arid regions of states like Rajasthan and Gujarat present prolonged periods of high temperature (>35 °C) and very low humidity (<50% RH).

While *Cheyletus malaccensis* demonstrated optimal performance under the controlled, high-humidity regimes of the present study, its efficacy in more variable, drier inland climates, where desiccation stress and thermal extremes are prevalent, cannot be directly extrapolated. Therefore, this study establishes a high-efficacy biocontrol benchmark for the warm, humid warehouses prevalent in coastal and northeastern India. For application across India's diverse climates, further research is essential to evaluate the predatory mite's adaptability, its potential for use in seasonal release programs, or the need for localized biotypes suited to the wider range of temperature and humidity regimes defining the nation's different storage ecosystems.

The findings from the present study, along with comparisons to published research from around the world, strongly indicate that *Cheyletus malaccensis* is an excellent candidate for controlling pest mites in warehouses and storage facilities. Additionally, since this research established successful mass-rearing methods and evaluated the predator’s feeding and reproductive performance under various temperature and humidity conditions, the results can help overcome the current shortage of commercially available *C. malaccensis* products for practical pest control.

CHAPTER VI

SUMMARY

6. SUMMARY

The study investigated the diversity and distribution of predatory mites associated with stored products across six districts of North Kerala viz., Kasaragod, Kannur, Kozhikode, Wayanad, Malappuram, and Palakkad. The survey primarily targeted large warehouses operated by both government and private entities. Government facilities included those managed by the Food Corporation of India (FCI), the Central and State Warehousing Corporations, and the Kerala State Civil Supplies Corporation (Supplyco).

A total of 63 edible stored products from 61 different storage facilities were examined. The survey documented 28 species of predatory mites belonging to 19 genera, 13 families, and 2 orders. Overall species richness was lower than expected, likely due to the extensive use of pesticides in storage environments, as well as the high mobility of predatory mites. Among the stored commodities, boiled rice, raw rice, and wheat supported the highest diversity of predatory mites. *Cheyletus malaccensis* and *Blattisocius keegani* were the most frequently encountered species, occurring in multiple storage facilities.

Several noteworthy and novel findings emerged from the study. *Storchia pacifica* (Stigmaeidae) was recorded for the first time in India. The genus *Storchia* itself had not been previously reported from the country. This record was accompanied by a redescription and the preparation of a diagnostic key to the known world species of the genus *Storchia*. Additional genera and species newly reported from India included *Acaropsella strioreticulata* (Cheyletidae), a newly discovered and published species. The genus *Acaropsella* is relatively small, with only nine described species, thereby enhancing the importance of the present record. Furthermore, *Balaustium murorum* (Erythraeidae), *Sejus carolinensis* (Sejidae), *Paraneognathus wangae* (Calligonellidae), and *Raphignathus neocardinalis* (Raphignathidae) were also recorded for the first time from India.

Two Bdellid mites, *Spinibdella ampulla* and *Spinibdella tabarii*, were newly documented from Indian storage habitats. Rare but ecologically significant occurrences included *Amblyseius indirae* (Phytoseiidae) in stored black pepper, reinforcing earlier reports of phytoseiid mites in such environments. *Hoploseius andamensis* (Blattisociidae) was recovered from stored oyster mushrooms and is reported here for the first time from mainland India. Furthermore, a new species, *Fessonia indica* (Smarididae), was described as part of this study.

While earlier Indian research primarily focused on pestiferous mites, the present findings contribute to the understanding of the diversity and potential of beneficial species in stored product environments. Notably, members of the family Laelapidae, such as *Stratiolaelaps scimitus* and *Euandrolaelaps karawaiewi*, were documented for the first time in India. These findings have important implications for pest management strategies in storage facilities. Several of the documented species from the genera *Cheyletus*, *Blattisocius*, and *Cunaxa* are known natural enemies of stored-product pests and can contribute to sustainable pest suppression. Moreover, the rare species identified during the survey, such as *Hoploseius andamensis* and *Balaustium murorum*, may represent underexplored resources for future biocontrol programs. These results add to the existing knowledge of predatory mites in India and underscore the potential of biological control strategies that reduce pesticide use while promoting the conservation and effectiveness of beneficial predatory mites in stored-product systems.

The developmental study conducted in the present work demonstrated that temperature exerted a stronger influence than humidity in determining key demographic parameters such as fecundity, development time, survival, and population growth in the evaluated species.

Three temperature regimes (25°C, 29°C, and 33°C) combined with three relative humidity (RH) levels (70%, 80%, and 90%) were tested. This combination was carefully chosen to ensure minimal overlap with previously published studies, with the exception of the 25 °C and 80% RH condition, which was included for comparative purposes. The comparisons revealed that even minor differences in temperature, humidity, and prey species type significantly affected the developmental biology of *Cheyletus malaccensis*. While several earlier studies have focused on this species, most did not match the conditions of the present investigation. The inconsistencies across studies may be attributed to regional biotypic variations, indicating that even within the same species, physiological responses can differ substantially due to geographic and ecological differences.

Importantly, no similar developmental studies on *Cheyletus malaccensis* have been previously conducted in southern India. The few available reports were carried out under different environmental conditions or with different prey species, and thus do not directly align with the present findings. This highlights the distinctiveness and relevance of the current study. Furthermore, *Suidasia nesbitti* was used as prey in this work and this diet selection not previously reported for *C. malaccensis*. Although this prey resulted in lower fecundity than

Acarus siro (as used in other studies), it yielded higher viable offspring and net reproductive rate, suggesting improved survival and long-term fitness under this diet which is an important consideration for biological control applications.

Temperature and relative humidity (RH) significantly influenced the life-history traits of *Cheyletus malaccensis*, with complex trade-offs between reproduction, development, and survival. The highest fecundity (292.60 ± 2.75 eggs) and net reproductive rate (R_0 = 108.10 ± 1.84) occurred at 25°C/70% RH, but this combination also resulted in prolonged development (17.12 ± 0.33 days) and moderate survival (70.0 ± 0.57%), limiting its ecological efficiency. An increase in humidity at 25 °C further impaired performance, with 25 °C/80% RH slowing development (22.60 ± 0.59 days) and reducing reproductive output (R_0 = 86.60 ± 3.49), while 25 °C/90% RH compromised both fecundity (172.00 ± 4.17 eggs) and survival (65.0 ± 0.77%).

In contrast, 29°C with 80% RH emerged as the most balanced and ecologically viable condition, offering shorter development time (13.25 ± 0.12 days), higher survival (78.2 ± 0.27%), and moderate fecundity (139.90 ± 2.83 eggs). Although its intrinsic growth rate (r_m = 0.251 ± 0.002) was lower than at 25°C, this combination optimized population sustainability by prioritizing faster turnover and resilience. 29°C/90% RH achieved the highest intrinsic rate (r_m = 0.292 ± 0.005) and shortest doubling time (2.38 ± 0.04 days), but at the cost of reduced fecundity (105.00 ± 2.99) and survival (70.4 ± 1.16%), making it less stable for long-term population growth.

At 33°C, thermal stress overrode humidity effects, causing severe declines in fecundity (e.g., 90.00 ± 3.56 eggs at 90% RH) and survival (40.1 ± 3.29%). Development accelerated (fastest: 10.30 ± 0.20 days at 33°C/90% RH), but the net reproductive rate collapsed (R_0 = 23.60 ± 2.27), reflecting unsustainable population growth. The influence of humidity became diminished at this temperature, particularly for developmental traits such as egg incubation, confirming temperature as the dominant stressor under extreme thermal conditions.

Adult longevity and sex ratio disruptions further underscored environmental sensitivity. Higher humidity (90% RH) consistently reduced lifespan, especially at elevated temperatures. Notably, sex ratios skewed under stress (e.g., 2:1 female bias at 33°C/90% RH), suggesting that experimental ploidy manipulation, combined with temperature-humidity stressors, can destabilize *C. malaccensis*' innate sex-determination system. This plasticity highlights how mites may adapt reproductive strategies to abiotic extremes.

In conclusion, while 25°C/70% RH maximizes reproduction, 29°C/80% RH offers the best compromise for field conditions, balancing development speed, survival, and reproductive output. The study underscores that no single optimum exists; instead, trade-offs dictate fitness under varying environments. These findings deepen our understanding of how abiotic stressors and their interactions shape predatory mite population dynamics and adaptive responses.

The study on the feeding biology of *Cheyletus malaccensis* revealed that predation efficiency is highly stage-specific, with adult females emerging as the most effective predators across all prey life stages. Adult females consumed significantly more prey than other developmental stages, attributed to their larger size, enhanced mobility, and higher metabolic demands related to reproduction. In contrast, larvae and protonymphs of the predator showed lower feeding rates, primarily targeting the most vulnerable prey stages such as eggs and larvae. Among prey stages of *Suidasia nesbitti*, larvae were found to be the most susceptible due to their soft cuticle, low mobility, and limited defences, followed by protonymphs and tritonymphs. Adult females of the prey were the least consumed, likely because of their thicker cuticles and stronger escape responses.

A significant predator-prey interaction demonstrated that predation patterns are shaped by morphological and behavioural constraints, reflecting optimal foraging strategies. Smaller predators preferred softer, less mobile prey, while adult predators exploited a broader range, including more defensive prey. The study also noted that prolonged starvation led to cannibalistic behavior in *C. malaccensis*, suggesting an adaptive survival mechanism. Overall, the findings highlighted a clear ecological hierarchy in both predator efficiency and prey vulnerability, supported by robust statistical evidence, and suggested the potential of adult *C. malaccensis*, especially females, as effective agents in biological control strategies targeting early developmental stages of pest mite populations.

Cheyletus malaccensis was successfully mass-reared on *Suidasia nesbitti* under controlled conditions (29 ± 1°C, 80 ± 5% RH and a 24-hour dark period), achieving a 36.5-fold population increase within 30 days, which demonstrated its high reproductive potential. However, extended rearing up to 60 days led to a significant decline in population (13.45-fold increase), likely due to environmental deterioration caused by the accumulation of nitrogenous waste (notably ammonia) and increased cannibalism resulting from prey scarcity. These findings underscore the importance of limiting rearing cycles to 30 days and regularly renewing cultures to maintain optimal productivity. No previous studies have reported a standardized mass-rearing protocol for *C. malaccensis*, making this the first of its kind. This also provides a well-founded rationale for selecting *C. malaccensis* in the present study, despite its previous use in various experimental contexts, as the current research introduces novel methodology and practical applications not addressed in earlier works.

Maintaining a constant temperature of 25 °C for mass rearing, especially in tropical regions, typically requires significant electricity use and expensive equipment, such as an environmental chamber. However, regions where temperature and humidity conditions average around 29 °C and 80% relative humidity (RH) for most of the year offer advantages by minimizing the need for energy-intensive cooling and humidification, thereby reducing reliance on costly environmental control systems.

As part of this study, a custom 3D-printed Petri dish was designed to enhance the rearing of *Cheyletus malaccensis*. The modified double-walled structure, incorporating a water-castor oil barrier, effectively prevented mite escape and overcame the limitations of conventional plaster-based dishes. The smooth, non-porous surface and black PLA material improved visibility and hygiene, enabling efficient handling, observation, and replication of cultures. This innovative setup offers a practical and reproducible tool for future research on predatory mites. Its applicability extends beyond *C. malaccensis*, providing a valuable resource for researchers working on the biology of various stored-product mite species.

In summary, this study advances the understanding of predatory mites in stored-product ecosystems through a comprehensive approach that includes taxonomy, biology, mass production, and novel methodological contributions. It provides a strong foundation for future research and biocontrol applications in post-harvest pest management.

CHAPTER VII

RECOMMENDATIONS

7. RECOMMENDATIONS

Overreliance on chemical fumigants and pesticides for managing postharvest pests, particularly in stored grains, pulses, cereals, and oilseeds, remains a dominant practice in India. This dependency persists largely due to the preference for quick results by warehouse operators, many of whom remain unaware of the health and ecological risks associated with prolonged chemical usage. Alarmingly, several of these substances have been used, both knowingly and unknowingly, for over five decades, potentially contributing to pesticide resistance among key pest species.

In contrast, many developed nations, particularly in Europe, have already recognized the associated risks and have moved towards safer, pesticide-free, and organic storage practices. Additionally, stricter international quarantine regulations now demand residue-free stored products. As the world’s largest producer of many agricultural commodities, India must align with this global shift by actively promoting organic and biological pest management strategies in postharvest systems.

The present study documented 28 species of predatory mites from storage habitats across northern Kerala, representing a significant contribution to the existing knowledge of regional biodiversity. However, this likely represents only a portion of the actual diversity. One of the major challenges encountered during the survey was limited access to private warehouses, supermarkets, and wholesale and retail storage units, largely due to unwillingness or mistrust from storekeepers. Nevertheless, successful collections were made from several government-operated warehouses through official channels.

To address the current knowledge gap, it is recommended that a comprehensive state- or nation-wide survey be conducted with the collaboration of government bodies, agricultural departments, and public health authorities. Such a coordinated effort would help uncover the full extent of the predatory mite fauna in private and public storage systems across Kerala and beyond.

The present research has also identified several species with potential biocontrol value, yet most of them remain unstudied in terms of their developmental biology and predatory behavior. Future research should prioritize evaluating these species in controlled settings to assess their practical utility in biological control programs.

Among the species studied, *Cheyletus malaccensis* was investigated in detail for its development and predation against the storage pest *Suidasia nesbitti*. The findings of this study confirm the species' effectiveness against *S. nesbitti* under South Indian conditions and demonstrate successful mass-rearing protocols. Notably, this research represents the first report of a mass-rearing method for *Cheyletus malaccensis*, providing a crucial step toward its practical use in large-scale biocontrol efforts. Despite being a well-studied species, no commercial formulation of *C. malaccensis* is currently available in the market. However, the present study has brought this goal within close reach, just one step away from realization. With appropriate support through collaborations with agricultural biocontrol companies or the launch of dedicated start-ups, commercialization can be effectively achieved.

The successful transition from controlled laboratory environments to commercial application necessitates a final phase of *in situ* validation. Before large-scale deployment, structured warehouse trials are required to evaluate the biocontrol potential of *Cheyletus malaccensis* under fluctuating environmental conditions. Utilizing a small-plot experimental design within storage facilities, the predatory efficiency and dispersal rates of the mites can be scientifically monitored in localized micro-plots. This tiered approach allows for the observation of population dynamics and hunting behavior within bulk commodities or stacked products. Such field-like testing is a critical prerequisite; it provides the empirical data required to determine precise release rates and ensures that the laboratory validated mass rearing methodology translates into a reliable, high-performance solution for real-world organic warehouse management.

Transitioning laboratory success to market availability requires a structured approach to technology transfer and product development. This study developed a novel 3D-printed rearing Petri dish that improves the handling and observation of mite cultures. This simple yet effective innovation overcomes several limitations of traditional plaster-based systems and holds promise for broader application in stored-product mite research. The refined mass-rearing protocol and the 3D-printed system offer a ready-to-scale toolkit for the bio-input industry. Commercialization efforts should focus on the formulation of mite-based products using biodegradable carrier materials that ensure high survival rates during transport and application. To realize this potential, there is significant scope for collaboration. Academic institutions and universities that provide the funding and equipment for such research are well-positioned to partner with agri-tech start-ups. These partnerships can spearhead the production of native biocontrol agents. This model would reduce the reliance on expensive, imported, and hazardous chemical alternatives while creating a decentralized and locally available, sustainable supply chain for organic warehouse management.

Given the cosmopolitan distribution of *C. malaccensis*, molecular characterization is essential to identify and distinguish regionally adapted biotypes, such as those in South India. Preliminary results from the present study suggest that the South Indian population exhibits better thermotolerance and higher fecundity compared to biotypes studied in other regions, such as Brazil, Egypt, Greece, and China. Future research should prioritize the mapping of trophic interactions between these predators and a wider array of primary storage pests, such as *Tribolium castaneum* and *Sitophilus oryzae*, to establish a comprehensive biological control matrix. Investigating the symbiotic relationships and the microbiome of these mites could also reveal endosymbionts that enhance their predatory efficiency or environmental resilience, providing a more robust framework for their application in diverse storage climates.

For biological control to be effective, it must be integrated into a broader Warehouse-Level Integrated Pest Management (IPM) framework rather than being treated as a standalone remedy. Predatory mites like *C. malaccensis* should be utilized for inoculative releases at the start of the storage season to suppress pest populations before they reach economic injury levels. However, the success of such a biocontrol program is heavily dependent on strict warehouse hygiene and environmental management. To ensure maximum efficiency and profitability, regular monitoring of humidity and temperature levels must be prioritized because these factors directly influence mite fecundity and pest development.

Furthermore, physical sanitation measures, such as the immediate removal of grain spillages, the repair of water leaks, and the prevention of bird and rodent entries, are essential to deny pests the nesting sites and moisture they require. Proper stacking and piling of sacks should also be ensured to facilitate airflow and allow for more uniform distribution of released predatory mites throughout the storage unit. By establishing these standardized operating procedures alongside detailed compatibility studies with other eco-friendly tools, including Diatomaceous Earth or botanical extracts, the innovations from this study can be transformed into a practical and multi-layered defence strategy for large-scale food reserves.

In conclusion, the findings of this study should be actively considered for integration into sustainable pest management strategies in storage environments. By harnessing the potential of native predatory mites and applying the methodological innovations introduced here, it is possible to move toward a more eco-friendly, health-conscious, and biologically sustainable approach to postharvest pest control.

The tools for this transition are now within reach. The next step is clear: adoption, scaling, and implementation represent an urgent and necessary investment in our agricultural future. This path forward promises not only to protect our stored harvests but also to safeguard the health of agricultural workers, consumers, and the environment, ultimately securing a resilient food system for the future.

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A new species of the genus *Acaropsella* (Acari: Trombidiformes: Cheyletidae) from Kerala, India

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Abstract

A new species, *Acaropsella strioreticulata* sp. nov. is described and illustrated herein from wheat semolina of Kerala state, South India. Additionally, this is first record of genus *Acaropsella* from India. Descriptions are based on the morphology of adult females.

Keywords: Acari, *Acaropsella*, new species, Kerala, India

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Introduction

Cheyletidae is a large family which presently includes 75 genera and over 440 species (Zhang et al. 2011; Beron 2021; Bochkov and Abramov 2016). Genus *Acaropsella* comprises relatively large cheylitids and was created by Volgin (1969) for those species of the genus *Acaropsis* Moquin-Tandon 1863 in which acicular humeral setae is absent. Genus *Acaropsella* can be characterized by having a single palp comb, two dorsal shields, a pair of propodosomal eyes, all legs with paired claws, elongate and narrowly expanded or spatulate dorsal setae (L.A Corpuz-Razos, 1998). According to Gerson et al. (1999), *Acaropsella* included nine species. Later Fain and Bochkov (2001) synonymized *Acaropsella aegyptiaca* Wafa et Soliman, 1968 with *A. volgini* Gerson, 1967; *A. filippina* Corpuz-Raros and *A. konoi* Tseng, 1977 with *A. kinshasensis* Fain, 1972. Consequently the species number of *Acaropsella* reduced to six. In 2007, Akbar et al. added two new species to this genus which resulted in the total of eight species of mite in the genus *Acaropsella*. This genus has not been reported from India so far. Thus, the work describes a new species *Acaropsella strioreticulata* sp. nov. from India, which is also a new record for India.

Materials And Methods

Samples of wheat semolina infested with mites were collected from Kozhikode district of Kerala state, South India (11° 22' 3.54" N, 75° 47' 35.74" E) and extracted using Berlese-Tullgren funnels equipped with 60 watt bulbs. and picked out under a stereo microscope. Extracted mites were kept temporarily in lactic acid for clearing. Hoyer's medium was used for making permanent slides. Illustrations and measurements were made using Olympus CX31 bright field microscope equipped with a drawing tube. Illustrations were scanned and redrawn using Adobe Illustrator® program (vector-based graphics software, Adobe Systems Incorporated, San Jose). Measurements were done with Lynx Biolux (Lawrence and Mayo) image analysis software. All body measurements presented as ranges (minimum to maximum), in micrometers (μm). The type materials are preserved as permanent slides and deposited in the Western Ghat Field Research Centre- Zoological Survey of India, Kozhikode,Kerala, India.

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Systematic Accounts

Material Examined: Holotype, Female, India, Kerala, Kozhikode. 23 September 2021. Paratype: four, four females. 11° 22' 3.54" N, 75° 47' 35.74" E, Altitude 13 m, 23-ix-2021, coll. Neeraj Martin (deposited at the Western Ghat Field Research Centre- Zoological Survey of India, Kozhikode, Kerala, India)

Description

***Acaropsella strioreticulata* sp. nov.**

Female (Fig.1-4)

Gnathosoma: (Fig. 3). Length 125 (122-127) and width 81 (79-82). Rostral shield has coarse robust pentagonal or hexagonal reticulation pattern. Rostrum tappers to blunt end. Tegmen is broader than protegmen. Palp femur have one spatulate dorsal setae of length 26 (25-26), two ventral setae and one dorsolateral seta. Transverse striations seen on palp femur. Palp tibia with one comb like seta with 13 teeth, two sickle like setae, palp claw with four teeth. Horse- shoe shaped periteme with six links on each side.

Idiosoma: (Fig. 1) Body ovoid, length 360 (352-366) and width 250 (244-254). Two dorsal shields are separated by transverse striation membrane of 34 (33-35) width. Both shields have prominent coarse pentagonal or hexagonal reticulation pattern. All dorsal setae are broadly spatulate and barbed. Propodosomal shield length 149 (146-151), width 166(162-169) and is trapezoidal. One pair of eyes are present which is placed off propodosomal shield. Propodosomal shield has four pairs of lateral setae Vi (25, 24-25), Ve (31, 30-32), Sci (29, 28-29) and Sce (31, 30-32) and three pairs of median setae d1(26, 25-26), d2 (26, 25-26) and d3 (25, 24-25) within the shield. Humeral setae of length 35(34-36) is similar to dorsal setae and is seen laterally on the membrane off the propodosomal shield. Hysterosomal shield of length 149(146-151) and width 166(162-169) bears four pairs oflateral setae L1 (31, 30-32), L2 (31, 30-32), L3 (31, 30-32), L4 (32, 31-33) and four pairs of median setae d4 (26, 25-26), d5 (26, 25-26), d6 (26, 25-26) and d7 (32, 31-33). Lateral setaL5 (34, 33-35) is placed caudally on membrane off the shield. Membranous area around the shield with striations seen.

Venter: (Fig. 2) All setae in the genital region are acicular. Genital setae g1 14(14), g2 16(16) and g3 16(16). Anal setae a1: 16(16) , a2: 26(25-26) and a3: 20(20) . Striations can be seen in the genito-anal region (fig. 2)

Legs: (Fig.4) Length of leg I (from coxae to tip of tarsi): 228 (223-232) , leg II: 195 (191-198) , leg III: 206 (201-209) and IV: 275 (269-280) . Ratio of leg I/ idiosoma= 0.63 (0.63-0.65), leg II/ idiosoma =0.54 (0.52-0.54), leg III/ idiosoma = 0.57 (0.56-0.58) and leg IV / idiosoma= 0.76 (0.73-0.76). Length of solenidion ω1 on tarsus I is 30 (29-30) μm and is supported by a small guard seta. Setae and solenidion in leg segments I-IV: coxae 2-1-2-2, trochanter 1-2-2-1, femur 2-2-2-1, genu 2-2-2-2, tibia 6-4-4-4 and tarsi 11-8-7-5. All leg segments except tarsi I- IV have transverse striation whereas tarsi I-IV have longitudinal striation. Tarsal claws have a terminal fork-like eupathidia.

Male: Not came in collection.

Diagnosis: *Acaropsella strioreticulata* **sp. nov.** is closely similar to *Acaropsella kinshasensis* Fain, 1972 and *A. filipina* Corpuz-Raros, 1998. The species *A. filipina* Corpuz- Raros, 1988 and *A. konoi* Tseng, 1977 are not different from *A. kinshasensis* Fain, 1972. All morphological the characters of these species, described by Corpuz-Raros (1988) and Tseng (1977) as "unique", i.e. the reticulate pattern on the stylophore and on the dorsal shields and also the fan-like dorsal seta of the palpal femur, are also present in *A. kinshasensis*. Hence, Fain and Bochkov (2001) considered *A. filipina* and *A. konoi* as junior synonyms of *A. kinshasensis*. *A. strioreticulata* sp. nov is similar to *A. kinshasensis* by having reticulation on rostrum and idiosoma, membranous separation between propodosomal and idiosomal shields, a total of 16 dorsal setae, L5 placed off the shield, comb seta with 13 processes and all anal setae simple acicular. *Acaropsella strioreticulata* sp.nov. clearly differs from *A. kinshasensis* by the presence of 4 palp teeth and by having propodosomal and hysterosomal shield of same length (ratio between the lengths of propodosomal shield and hysterosomal shield is 1 in *A. strioreticulata* sp.nov and 0.78 in *A. kinshasensis*). Whereas, in *A. kinshasensis* 5-6 palp teeth present and hysterosomal shield is longer than propodosomal shield. All setae of tibia I is hair-like in *A. kinshasensis* whereas, in *A. strioreticulata* sp.nov all setae on tibia I is simple except one thickened setae (immature form of fan-like setae). *A. kinshasensis* possesses one fan-like seta on tibia III, while, *A. strioreticulata* sp.nov does not have such fan-like setae on tibia III. Three sickle setae are found in *A. filipina* whereas only 2 sickle setae is observed in *A. strioreticulata* sp. nov. Chaetotaxy of femur I-IV is 2-2-2-1 in *A. strioreticulata* sp.nov but it is 2-2-1-1 in *A. filipina.* In *A. strioreticulata* sp.nov, eyes are placed off propodosomal shield whereas in *A. filipina*, eyes are located within the antero-lateral margins of propodosomal shield.

Chaetotaxy of tarsi I-IV (including solenidion) is 11-8-7-5 in *A. strioreticulata* whereas it is 6-5-4-4 in *A. filipina*. All leg segments are transversely striated except tarsi which is longitudinally striated in *A. strioreticulata* **sp. nov**. and *A. shaziai*. This morphological feature is absent in other *Acaropsella* species. *A. strioreticulata* sp.nov. can be separated from *A. schmidtmanni, A.rohdendorfi* and *A.volgini* by the presence of coarse robust pentagonal or hexagonal reticulation on rostral and idiosomal shield , whereas it is absent in *A. schmidtmanni* , *A.rohdendorfi* and *A.volgini*. This specimen can be separated from *A.nobilis* and *A.kulagini* by the presence of four palp teeth whereas *A.nobilis* and *A.kulagini* have six palp teeth. *Acaropsella strioreticulata* sp.nov. differ from *A.shazai and A. walli* by the presence of 13 processes on comb seta and dorsal seta L5 out of theshield. In *A. shazai and A. walli* 16 processes present on comb seta and dorsal setae L5 is out of the shield along with L1 and L4.

Etymology: The specimen has been named after their morphological features.

Key to females species of the genus *Acaropsella*

1. Total number of dorsal setae equal or more than 17 ----------------------- *A. nobilis* Rasool, Chaudhri &Akbar, 1980
   -total number of dorsal setae less than 17 --2

2. Setae d2 situated off from propodosomal shield --- *A. schmidtmanni* Price, 1972
   -setae d2 situated on propodosomal shield ---3

3. Peritreme with more than 6 links --4
   -Peritreme with less than 6 links---5

4. Peritreme with 7 links-- *A. rohdendorfi* Volgin,1962
   -Peritreme with 8 links --- *A. shaziai* Akbar, Jahan & Mughal, 2008

5. Hysterosomal shield longer than propodosomal shield, palpal teeth equal or more than 5 in number---------------------6
   -Hysterosomal shield and propodosomal shields almost similar in length, Palpal teeth less than 5 in number.-------------8

6. Propodosomal and hysterosomal shields are separated by membranous area Dorsal setae on genu I-II fan like ----------7
   - Propodosomal and hysterosomal shields are not separated by membranous area Dorsal setae on genu I-II hair like--*A . kulagini* Rohdendorf, 1940

7. Rostral and idiosomal shield with network pattern--- *A. kinshasensis* Fain, 1972
   -Rostral and idiosomal shield without network pattern--*A. volgini* Gerson,1967

8. Comb setae with 13 process, setae L1 and L2 situated on hysterosomal shield, striation pattern present on membranous area around propodosomal and hysterosomal shield, femur IV with one setae…………………………..…….***A. strioreticulata* sp.nov**

   -Comb setae with 16 process, setae L1 and L2 situated off hysterosomal shield,striation pattern absent on membranous area around propodosomal and hysterosomal shield, femur IV without setae…………………………..*A. walii* Akbar, Jahan & Mughal, 2008

FIGURES

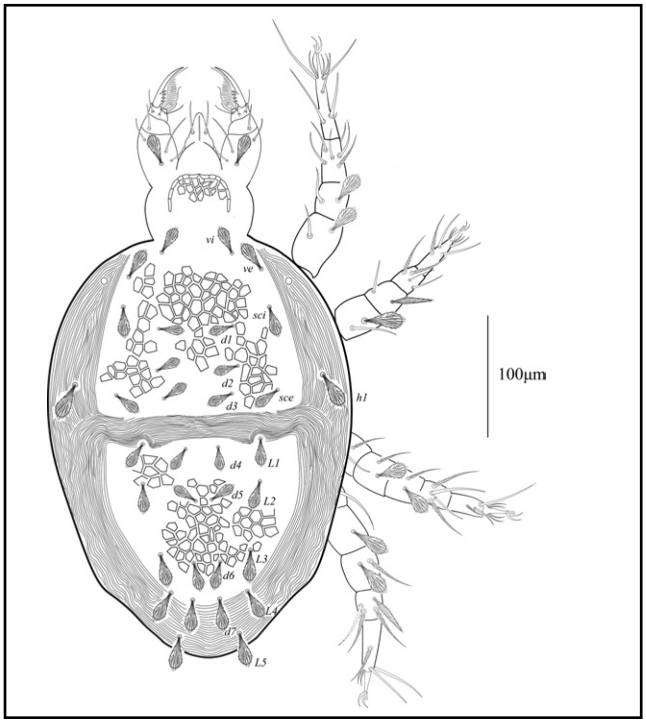

Figure 1: *Acaropsella strioreticulata* sp.nov. holotype female. Dorsal idiosoma

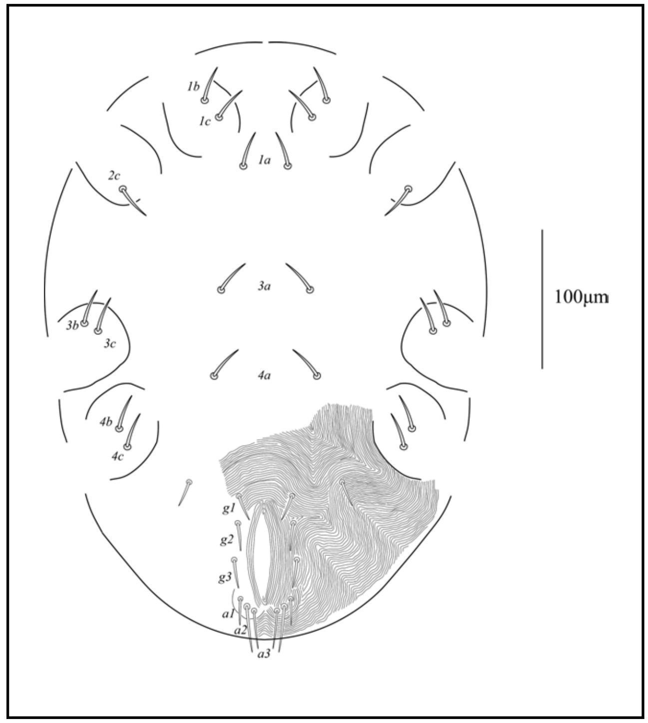

Figure 2: *Acaropsella strioreticulata* sp.nov. holotype female. Ventral idiosoma.

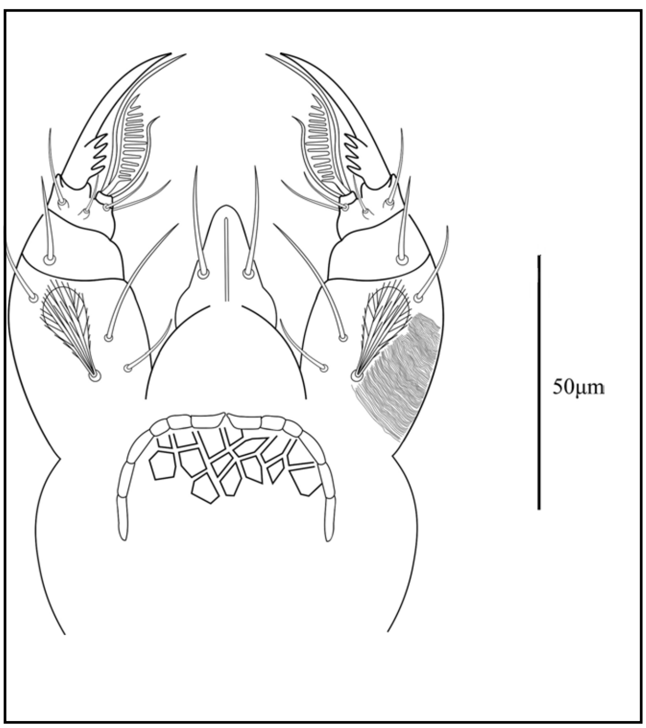

Figure 3: *Acaropsella strioreticulata* sp.nov. holotype female. Gnathosoma

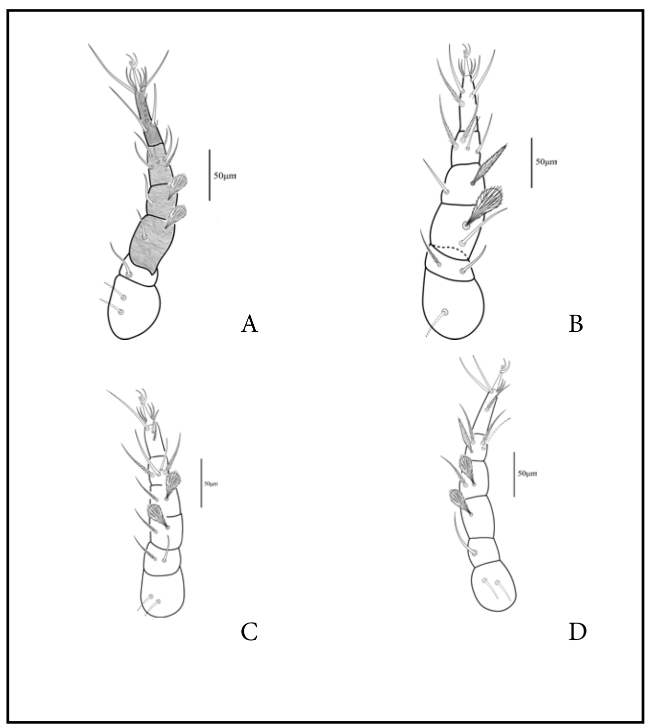

Figure 4: *Acaropsella strioreticulata* sp.nov. holotype female. A. leg I, B. leg II, C. legIII, D. leg IV.

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Description of a new species of the genus *Fessonia* (Acari: Trombidiformes: Smarididae) from Kerala, India

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Abstract

A new species of the genus *Fessonia* (family: Smarididae) viz., *Fessonia indica* sp. nov. has been collected from rice from Kerala state, South India, which is described and illustrated. So far, two species of the genus *Fessonia* have been reported in India. Descriptions are based on the morphology of post larval instar. A key to the Indian species is also provided.

Keywords: Morphology, New Record, Predatory Mite, Smaridid Mite, Taxonomy

Introduction

The superfamily Erythraeoidea is one of the largest superfamilies under the cohort Parasitengona (Acari: Trombidiformes). Erythraeoidea comprises two families *viz*., Smarididae and Erythraeidae. Smaridids represent a distinctive cohort of mites, distinguished by an extensible gnathosoma carrying the mouthparts during postlarval instars. These mites typically exhibit an oval idiosoma, and elongated legs, and possess either one or two pairs of eyes, as illustrated by Meyer and Ryke in 1959. The legs and idiosoma are commonly adorned with dense, occasionally cactus-like hairs. Dorsally, these mites feature a pair of sensillary areas that may be interconnected or remain discrete, delineated by a narrow furrow referred to as the crista metopica. Smaridids are a fairly small family; the catalogue of Beron (2008) recognized 55 living species/ subspecies in 11 genera, later Zhang *et al*., (2011), and Zhang (2011) revised it to 10 genera and 53 species which is then subsequently emended to 49 species in nine genera by Makol and Wohltmann (2012). A further species was described by Salarzehi *et al*., (2012). Recently, Bartel *et al.*, (2015) described 3 species of post-larval fossil Smaridid mites from Baltic amber. Fourty-one species of Smarididae are known exclusively from active postlarval forms, seven from larvae, and only five from both. Smaridids can be found throughout the world, except for Antarctica, and are known to occur in grassland and litter habitats (e.g. Southcott 1961, 1963, 1995, 1996; Krantz & Walter 2009). Mites under the family Smarididae are classified into two subfamilies, Smaridinae and Hirstiosomatinae. Smaridinae consists of five genera including *Fessonia* von Heyden 1826.

The taxonomic classification denoted as Genus *Fessonia* presently encompasses a total of 14 recognized species, of which nine have been delineated based on adult specimens. Two Fessonia mite species have been characterized exclusively from their larval stages, namely *F. torshizica* (Salarzehi & Hajiqanbar, 2012) and *F. papillosa* (Hermann 1804). The former is indigenous to Iran, while the latter was previously documented in the European region (Wohltmann 2010). During a faunistic survey conducted to assess mites associated with stored food products in North Kerala, South India, from 2019 to 2022, a *Fessonia* species was discovered inhabiting rice. Notably, there are no prior records documenting the presence of *Fessonia* mites in stored food products, suggesting that this occurrence may be incidental. Subsequent investigations confirmed that the identified species is novel to scientific classification. Until the present study, only two *Fessonia* species had been reported in India: *F. assimuthi* (Oudemans, 1941) and *F. australiensis* (Southcott, 1946). Consequently, the discovery of this species contributes to the enumeration of Indian *Fessonia* species, bringing the total to three.

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Materials and Methods

Samples of rice infested with mites were collected from the Kasaragod district of Kerala state, South India (12° 15' 26.4093" N, 75° 8' 7.278" E). The samples were examined using a Magnus Stereozoom microscope, and mites were collected using a camel hair brush moistened with water. Extracted mites were kept temporarily in lactic acid for clearing. Hoyer's medium was used for making permanent slides. Illustrations and measurements were made using an Olympus CX31 brightfield microscope equipped with a drawing tube. Illustrations were scanned and redrawn using the Adobe Illustrator® program (vector-based graphics software, Adobe Systems Incorporated, San Jose). Measurements were done with Lynx Biolux (Lawrence and Mayo, India) image analysis software. All body measurements are presented in micrometres (µm). Measurements of paratype are provided in parenthesis.

Terminology and abbreviations follow those of Grandjean (1947) and Wohltmann (2010). The type materials are preserved as permanent slides and deposited in the Western Ghat Field Research Centre- Zoological Survey of India, Kozhikode, Kerala, India.

ZooBank registration number : urn:lsid:zoobank.org:pub:669D3CE3-0551-4FE1- 8B73-F33E6B7268D9.

Results and Discussion

Material examined: Holotype, post larval instar. Location: Kasaragod district (Food Corporation of India warehouse, 12° 15' 26.4093" N, 75° 8' 7.278" E) Kerala state, India. Collected on 19th November 2020 from rice. Paratype: 1 (one post larval instar).

Type deposition: Holotype (ZSI/WGRC/I.R.INV.25577) and 1 paratype (ZSI/WGRC/I.R.INV.25578) deposited at the Western Ghat Field Research Centre- Zoological Survey of India, Kozhikode, Kerala, India.

Description
Fessonia indica sp. nov.
Post larval instar-Holotype.

Dorsum (Figure 1*):* Idiosoma 518 (620) long from tip of naso to posterior end of opisthosoma, 258 (308) wide near mid-idiosoma. Crista metopica (Figure 5) nearly extends to mid-diosoma but does not reach the level of leg III bases. The anterior sensillary area is located posteromedial of two pairs of eyes [94 (112) from the tip of propodosoma], with a single seta which is 16 (19) long (normal dorsal setae). Anterior sensilla ciliated, 46 (55) long; their bases 7 (8) apart. Posterior sensilla ciliated, 41 (49) long, 40 (47) away from anterior one and bases 15 (17) apart. Two pairs of eyes of unequal size; anterior eyes 20 (24) in diameter, posterior eyes 14 (17), located slightly posterolateral of anterior eyes. Dorsal setae (Figure 6) are broader 18 (21) long, numerous, brown and dorsally convex as in *F. australiensis*. There with 6-8 lines of serrations, which extend longitudinally to the pedicel of the seta. Ventral surface of dorsal setae flattened. The ratio between the length of idiosoma and the distance between ASA to PSA is 12.95. **Ventrum** (Figure 2): Ventral setae (Figure 7) with strong ciliations (lanceolate pattern), setae 13-22 (15-26) long (slightly smaller than dorsal setae). Genital pore without any surrounding setae.

Legs (Figure 10-13)*:* Legs (coxae to tarsus) covered with long and pointed spiculated setae (Figure 8).

Measurements of lengths of leg I (Figure 10): coxa 77 (92), trochanter 53 (64), basifemur 90 (108), telofemur 111 (134), genu 151 (181), tibia 152 (181), tarsus 163 (195). Tarsus features two specialized setae (Figure 9) that bear a resemblance to solenidion. These setae are also found on the tibia, genu, and telofemur, with one of these setae present on each of these leg segments.

Measurements of lengths of leg II (Figure 11): coxa 81(96), trochanter 44 (53), basifemur 45 (54), telofemur 65 (78), genu 81 (97), tibia 102 (122), tarsus 62 (74)**.**

Measurements of lengths of leg III (Figure 12): coxa 80 (96), trochanter 62 (74), basifemur 57 (68), telofemur 70 (83), genu 94 (112), tibia 117 (140), tarsus 71 (85).

Measurements of lengths of leg IV (Figure 13): coxa 75 (89), trochanter 56 (67), basifemur 60 (72), telofemur 107 (128), genu 124 (148), tibia 134 (160), tarsus 91 (109). All tarsi terminated with paired claws. Details of leg chaetotaxy are provided in Table 1.

Gnathosoma (Figure 3): Gnathosoma 110 (131) long, retractable. Chelicerae 55 (65) long. Cheliceral digits short, 4 (5) long. Dorsal gnathosoma with a pair of smooth, pointed adoral setae *cs* 9 (11) anteriorly and ventrally with a pair of smooth and pointed subcapitular (tritorostral) setae *bs* 23 (27) and oral setae *as* 18 (23). Palpal trochanter 17 (20) long. The palpal femur is 45 (54) long with four long dorsal setae and one ventral seta, and the length ranges from 12-25 (14-30). Palpal genu 25 (30) long with four dorsal setae, and 2 ventral setae. Palpal tibia with four setae. Odontus not bifurcated 21 (25) long. All setae from palpal femur to palp tibia are similar to leg setae. Palpal tarsus (Figure 4) 15 (18) long with four smooth setae *gc* 7 (8), *ds* 5 (4), *hc* 9 (11), *nc* 20 (24) one solenidion (*w*) and two prominent distal eupathidium (*z*).

Larval and adult stages: Unknown.

1

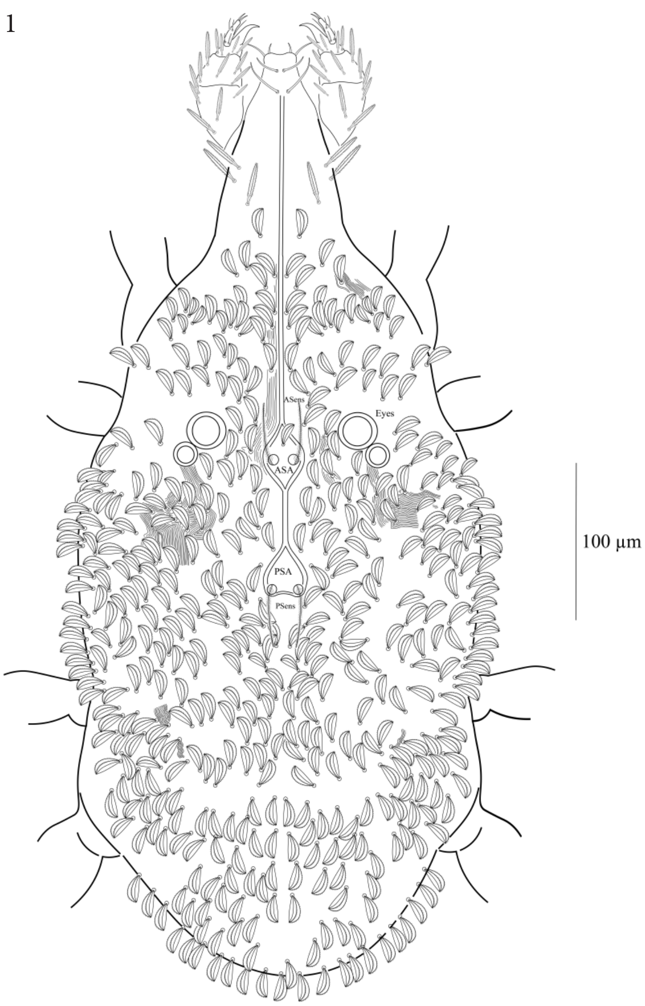

Figure 1: *Fessonia indica* sp.nov. holotype post-larva. Dorsal idiosoma.

Etymology

The species' name is a reference to its native country of origin, India.

Remarks

Trichobothria are conspicuously absent on the legs of post larval active instars of Smarididae, occurring solely during the larval stage, as documented by Grandjean in 1947. The distinctive characteristics that set *Fessonia indica* apart from other species within the genus *Fessonia* include the quantitative differentiation in the number of setae on tarsi I and the notable presence of solenidion-like specialized setae on legs I-IV in post-larval active instars. Furthermore, *F. indica* sp. nov. can be easily differentiated from other known species within the genus *Fessonia* due to its notably short distance between ASA and PSA.

The only other known *Fessonia* species in India are *F. australiensis* Southcott, 1946 and *F. assimuthi* Oudemans, 1941. *Fessonia indica* can be discerned from other extant species within the genus *Fessonia*, with the

2

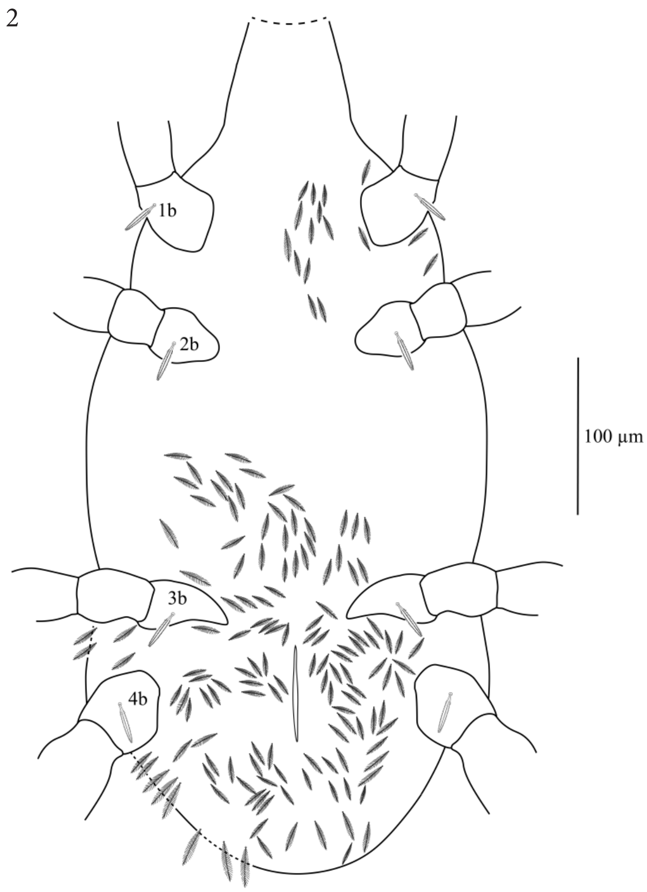

Figure 2: *Fessonia indica* sp.nov. holotype post-larva. Ventral idiosoma

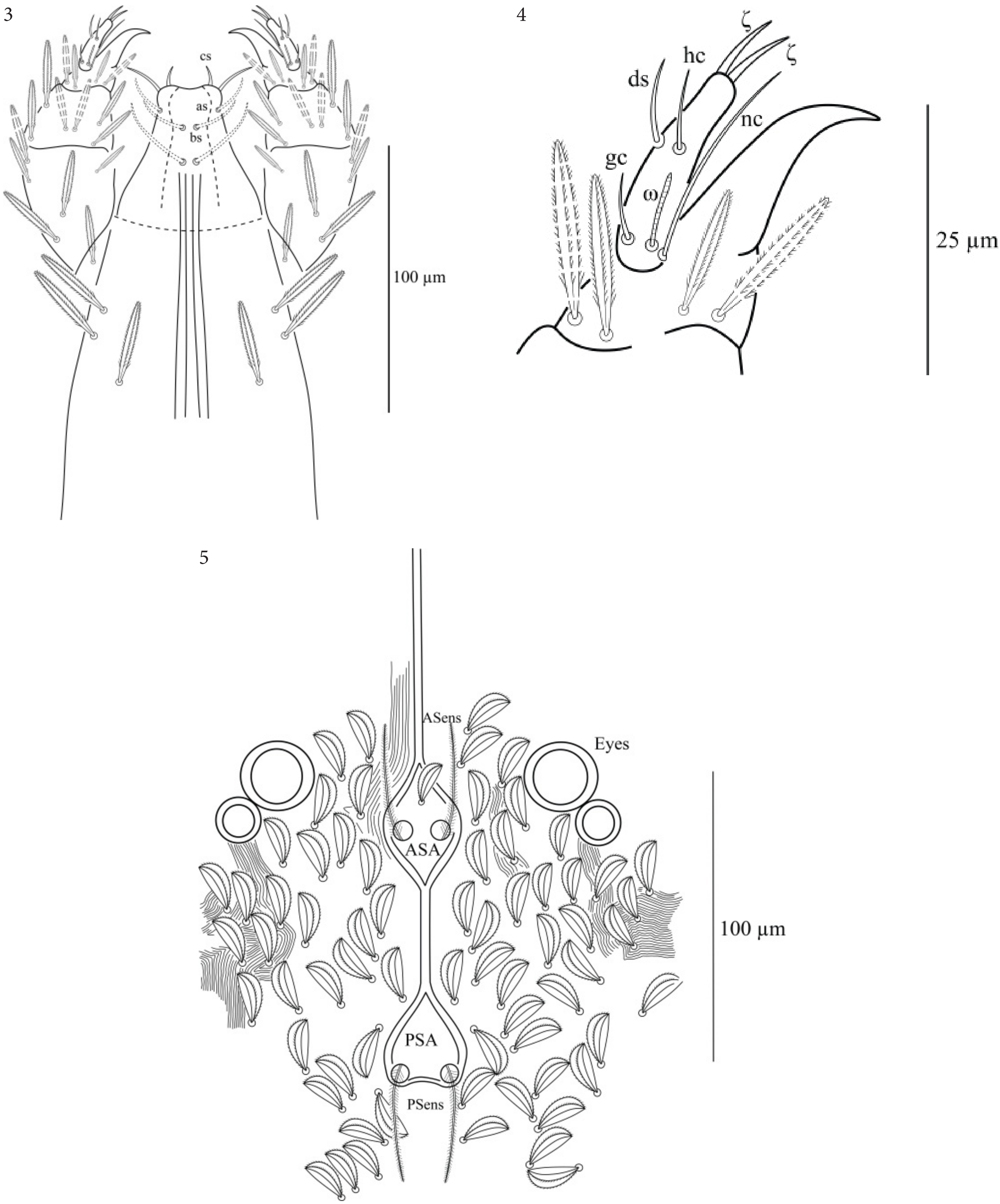

Figure 3-5: *Fessonia indica* sp. nov. holotype post-larva **3**) Gnathosoma; **4**) palpal tibia and tarsus **5**) crista of metopica.

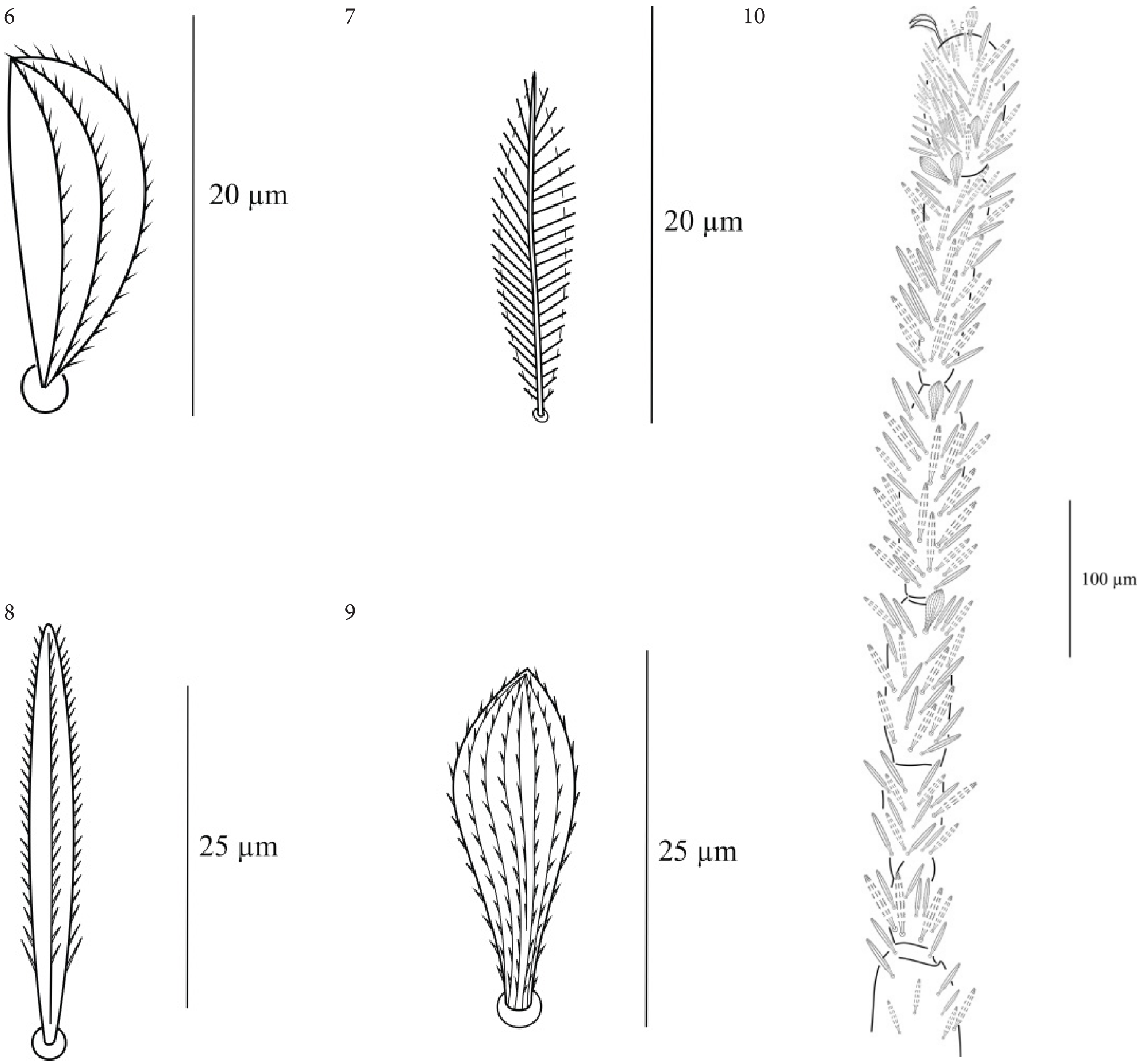

Figure 6-10: *Fessonia indica* sp.nov. holotype post-larva. **6**) dorsal seta; **7**) ventral seta **8**) leg seta **9**) specialized seta on leg I, III & IV **10**) Leg I

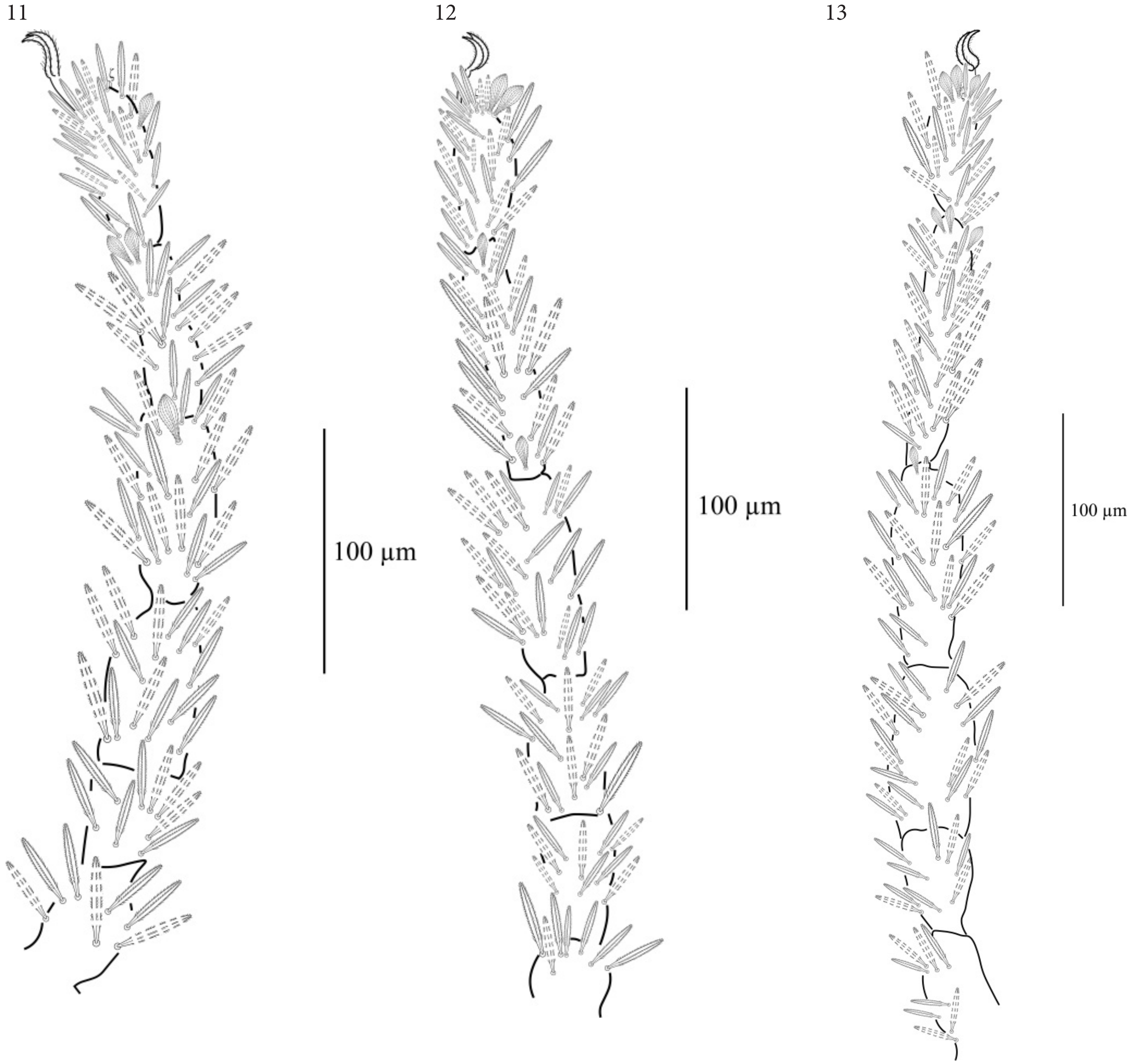

Figure 11-13: *Fessonia indica* sp.nov. holotype post-larva. **11**) Leg II; **12**) Leg III; **13**) Leg IV.

notable exception of *F. australiensis* and *F. assimuthi*, by the distinct morphological features exhibited by its dorsal setae. *F. indica* shares certain morphological features with *F. australiensis* and *F. assimuthi* but exhibits significant differences. Same type of dorsal setae is present on *F. indica* and *F. australiensis*. In *F. assimuthi*, there is a consistent reduction in the length of leg setae along the distal axis, exemplified by a decrease from 50 μm on the trochanter to 30 μm on the tibia. Conversely, no discernible variation in leg setal length is observed in *F. indica*. In *F. australiensis*, the anterior sensillary area features two setae, while in *F. indica*, only one seta is observed. The ventral setae of *F. indica* are strongly ciliated in a lanceolate pattern. The ratio between the length of idiosoma (from the tip of naso to the posterior end of opisthosoma) and the distance between ASA to PSA is 12.95 in *F. indica*., whereas it is 5.82 and 4.16 in *F. australiensis* and *F. assimuthi* respectively. The ratio between the length of leg I and the length of idiosoma is 1.29 in *F. assimuthi* and 1.53 in *F. indica*. *F. indica* is distinctive from *Fessonia papilossa* by virtue of

Table 1. Leg chaetotaxy of post larval instar of *Fessonia indica* sp. nov

Palpal Tr	1 N
Palpal Fe	5 N
Palpal Ge	6 N
Palpal Ti	4 N
Palpal Ta	4 N, 2 ζ, 1 ω
Cx I	1 N
Tr I	9 N
Bf I	22 N
Tf I	21 N, 1 specialized seta
Ge I	30 N, 1 specialized seta
Ti I	36 N, 2 specialized setae
Ta I	67 N, 2 specialized setae, 1 ζ
Cx II	1 N
Tr II	7 N
Bf II	8 N
Tf II	14 N
Ge II	20 N, 1 specialized seta
Ti II	15 N, 2 specialized setae
Ta II	27 N, 1 specialized seta, 1 ζ
Cx III	1 N
Tr III	7 N
Bf III	9 N
Tf III	14 N
Ge III	20 N
Ti III	21 N, 2 specialized setae
Ta III	24 N, 2 specialized setae, 1 ζ
Cx IV	1 N
Tr IV	8 N
Bf IV	9 N
Tf IV	18 N
Ge IV	19 N, 1 specialized seta
Ti IV	23 N, 3 specialized setae
Ta IV	22 N, 3 specialized setae, 1 ζ

possessing two palp tarsus eupathidia. Furthermore, in *F. papillosa*, the palp odontus exhibits bifurcation, whereas in *F. indica*, it remains non-bifurcated. Within the taxonomic context of *Fessonia torshizica*, it is observed that the palp odontus assumes a bifid morphology. *F. indica* can be differentiated from both *F. torshizica* and *F. papillosa* based on the quantitative distinction in the number of setae on the palpal tibia. Specifically, *F. indica* possesses four setae on the palpal tibia, while *F. torshizica* and *F. papillosa* each exhibit three setae on the palp tibia.

Key to the Indian species of the genus *Fessonia*

1. Anterior sensillary area with single seta in addition to trichobothria 2

-Anterior sensillary area with two setae in addition to trichobothria ....***F. australiensis***

2. Crista of metopica reaching the base of leg III, palptarsus with 3 terminal eupathidia ....***F. assimuthi***

-Crista of metopica not reaching the base of leg III, palptarsus with 2 terminal eupathidia......***F. indica*** sp. nov

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