BIOPROCESSING OF ORGANIC RESIDUES THROUGH ORICULTURE TECHNOLOGY

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ALPHONSA XAVIER

DIVISION OF ACAROLOGY
DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
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DECLARATION

I, ALPHONSA XAVIER, hereby declare that this thesis entitled **"BIOPROCESSING OF ORGANIC RESIDUES THROUGH ORICULTURE TECHNOLOGY"** has not been submitted by me for the award of any degree, diploma, title or recognition before.

Calicut University Campus
Date: 24.03.2004

ALPHONSA XAVIER

CERTIFICATE

This is to certify that this thesis is an authentic record of the work carried out by **Mrs. ALPHONSA XAVIER** under my supervision and guidance in partial fulfilment of the requirements of the degree of Doctor of Philosophy in Zoology, under the faculty of science of the University of Calicut. No part of this work has been presented before for any other degree. I also certify that **Mrs. ALPHONSA XAVIER**, has passed the M. Phil. Degree examination held in 1990.

Calicut University
24/03/2004

Dr. M. A. HAQ
SMIS DALE
Kohinoor
Thenhipalam P. O.
Malappuram - 673 636
Ph: 0494 - 2400505
0494 – 2400276
Email: haqma@sancharnet.in

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PART I
INTRODUCTION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

PART I
TAXONOMY OF ORIBATID MITES

INTRODUCTION

Acarology has gained tremendous significance recently as it triggered the study of a group of cryptic organisms capable of exerting far reaching influence on the welfare of humanity. The subclass Acari, coming under the class Arachnida comprises two distinct groups of animals - ticks which are generally ectoparasitic on higher vertebrates and mites enjoying cosmopolitan distribution with a wide variety of forms, habits and function. Ticks were known since the recorded time of history due to damages caused by them to man and his live-stock because of their parasitic life and larger body size. But mites remained obscure for a long time mainly because of their microscopic size, cryptic nature and scanty information on their economic importance. Quite surprisingly, the last few decades of the twentieth century witnessed a spurt of scientific activity on mites which shed light on the extent of influence they have on all possible human activities ranging from agriculture to post-mortem studies.

Mites represent a marvellous assemblage of organisms derived along distinct- phylogenetic lines and occupy the supreme position among chelicerate arthropods. They rival insects in exploiting

successfully even the most unpredictable environmental conditions. They thrive surprisingly in the abysmal depths of the ocean floor, the snow clad mountain peaks, the dreary deserts, thermal springs and even in the remnants of volcanic eruptions. Their extensive sensitivity rendered them to opt life styles ranging from free-living through parasites, predators to commensals. Their influence on various fields of human interest though helped to elevate their status as agents of positive order, examples of negative order very often exceed the former. In this context, pest, parasite and vector status of mites account for their negative effects while biodegradation, bioindication, biological control, predation etc. accord positive roles to them.

The two superfamilies, Tetranychoidea and Eriophyoidea represent true phytophagous mites which feed exclusively on higher plants. Quite often, mite infestation results in extensive damage to their host plants and unbearable economic loss to farmers. The recent outbreak of the coconut mite, *Aceria guerreronis* in most parts of Kerala is a well illustrated example. The pest status of the oribatid mite, *Paralamellobates bangalensis* affecting the common tuber crop *Dioscorea alata* is now an established fact. Field and plantation crops, vegetables and fruits, tubers, corms and rhizomes, garden and ornamental plants are all reported to be under different levels of pest attack due to the

feeding activity of various groups of phytophagous mites. The mouthparts of these mites are highly modified to feed on plant tissues by sucking the sap or to tunnel the shoot and root systems. These activities of the mites manifest in the host plants in several ways causing morphological, anatomical and physiological malformations like yellowing, russeting, chlorosis, necrosis, formation of blisters, erinea, galls, leaf rolling, premature falling of flower buds and fruits and stunted growth. In addition to these direct damages to the host plants, a few species of mites act as vectors transmitting pathogenic agents like viruses, bacteria and fungi.

The Acarine order Astigmata constitutes the notorious group of mites which lead a luxurious life in stored products like almost all types of food grains and oil seeds, spices and confectionaries, leather and wool items, cattle and poultry feed, fishery products etc. *Glycyphagus hughesi* and, *Aceria tulipae* cause serious damage to stored wheat, *Carpoglyphus lactis* destroys dried fruits, *Acaropsis tyrophagus* and *Cheyletus egypticus* thrive in milled wheat, *Tyrophagus lini* occurs in Bengal gram, *Suidasia medanensis* on dried fish, *C. lactis* on dried plum, *T. putrescentiae* on stored arecanut and *Lardoglyphus konoi* on poultry feed are but a few examples to cite.

The biological activities of mites reduce the quality and quantity of these stored items to devastating levels. The mites feed voraciously on the germ tissue and surrounding endosperm and contaminate them with their excreta and dead bodies. The nitrogen contents of the seeds are reduced to very low levels rendering them unfit for agricultural purposes. Large scale infestation leads to increase in temperature and moisture content of the stored material, inviting infection by microbes. This may cause various types of health hazards to animals and man who consume/handle these infested products.

Associations of mites with animals range from simple phoresy to active ecto and endoparasitism. Mites are known to inhabit hair follicles and fur of mammals, feathers and quill cavities and respiratory tracts of many vertebrates. Mites are reported from nests of birds, cages of animals and household furnitures. The damages caused by these parasitic mites can be the direct result of their feeding activities on blood, body fluids and other tissues of their hosts or indirectly by transmitting pathogenic viruses, bacteria, protozoa, ricketsia, nematodes, cestodes and the like.

An example of direct association between man and mite is exemplified through their parasitic interaction with man himself. The causative organism of human scabies is the common itch mite, *Sarcoptes*

scabei. The follicle mite *Demodex follicularum* invades hair follicles. Skin irritations like mange, vanillism, copra itch, grocer's itch etc. are also the manifestations of mite attack. It is a proven fact that certain diseases like scrub typhus, plague and epidemic haemorrhagic fever are transmitted by several species of mesostigmatid mites. The principal allergen of human sniffles and sneezes is the house dust mite *Dermatophagoides farinae* or *D. pteronyssinus.*

Acarine parasites of domesticated and other animals have given a notorious status to mites in the field of veterinary science also. In cattle, sarcoptic and psoroptic mange are mite induced health hazards. Certain species of oribatid mites belonging to the superfamilies Oribatuloidea, Ceratozetoidea, Oribatelloidea and Galumnoidea have been proved to be successful agents in transmitting cestode parasites among cattle. Experimental studies proved the transmission of *Moniezia expansa* to the primary host by the oribatid vector, *Galumna flabellifera orientalis* and *Hypozetes imitator.* Other cestode members like *M. benedini* and *Thysaniezia ovilla* were found transmitted by *Galumna* sp. and *Scheloribates* sp. Mite infestations in domestic animals culminate in loss of vigour, while sarcoptic and psoroptic mites cause weeping lesions. Mites have become a serious threat to apiculture due to their ecto and endoparasitic relationship with honeybees.

The foregoing account of interactions of mites with man and his surroundings created a stigma on mites as noxious and objectionable animals to common man and scientific community. This should be realized based on our ignorance on these groups of animals even today. However, evidences are now available along altogether unexpected lines which not only reverse the earlier concept about mites, but also attribute multitude of their beneficial roles. This covers a vast expanse of human interest involving maintenance of soil fertility, bioindication of soil conditions and biological control of pests and parasites injurious to plants and animals.

India being an agricultural country primarily, the fertility of soil is of utmost importance . The richness and variety of soil in different parts of the country provide an ideal habitat where a wonderful array of mites thrive luxuriously. The very fact that almost fifty percent of the known seven thousand and odd species of oribatid mites are denizens of soil proves that they form a significant group among the soil mesofauna. Among the various groups of the soil mites, the maximum credit goes to the oribatid mites because of their vital role in the break down of organic litter there by helping in the soil humification process. This they achieve through their diverse feeding

habits, with the help of highly specialised and modified mouth parts and a variety of microbial colonies harbouring in their gut.

Members of lower oribatid mites belonging to the superfamilies Phthiracaroidea, Lohmannoidea and Nothroidea are voracious feeders of wood and leafy litter of higher plant origin and hence several of them are categorised as macrophytophages. Certain brachypyline oribatid mites coming under the superfamilies. Eremuloidea, Oppioidea, Oribatuloidea and Galumnoidea assist the process of biodegradation indirectly by catalysing microbial activity within the soil ecosystem and are designated as microphytophages. Yet another group of soil mites play a dual role by feeding on both higher and lower plants depending on availability and they are classified as panphytophages. Many members coming under the superfamilies Eiplohmannoidea, Nothroidea, Eremuloidea. Oribatuloidea and Galumnoidea are a few examples of this category of mites. Higher oribatids like Eremuloidea, Oribatuloidea and Galumnoidea are excellent members of soil community enhancing the process of fungal dissemination. Feeding activities of these mites convert the complex organic substances into simple and easily degradable compounds.

Some detritiphagous mites devour dead roots which increase soil porosity and the formation of humus enriched subterranean

galleries. The direct participation of oribatid mites in the break down of organic litter results in nutrient release. Soil enriched with acarine faecal pellets provide a highly fertile environment, enhancing germination of seeds and healthy growth of roots. Thus, oribatid mites serve as indispensable link in biodegradation of organic litter and nutrient cycling. This spectrum of mite activity is an excellent illustration of competitive exclusion and mutual co-existence of a wide variety of species in the same habitat which enable these organisms to occupy all possible ecological niches.

Some oribatid mites are extremely sensitive to changes in the microclimatic conditions. This aspect of acarine behaviour is now being utilized for evaluating physiochemical characteristics prevailing in the soil ecosystem and to charter various agronomic practices. Oribatid mites belonging to various genera exhibit horizontal and vertical migrations for coping with the changes in their habitats. Seasonal migrations of these mites to the plant coverage has been correlated with behavioural adaptation to temperature and humidity. Some oribatid representatives like *Oppia translamellata* and *Heptacarus hirsutus* are reported to possess a close association with moist habitat and hence serve as indicators of humid conditions. Two other species viz., *Tectocepheus velatus* and *Malaconothrus globiger* are also good

indicators of wet condition. Contrarily, preference to dry habitat is well evidenced in several other species there by establishing a negative correlation with moisture. The prostigmatid mite, *Variatipes quadrangularis* is an indicator of dry condition.

Apart from their reaction towards physical factors like temperature and humidity, oribatid mites are also known to respond to chemical factors in the soil. The oribatid mite density is directly proportional to the organic content of the soil. These mites have been recognized as agents for the indication of organic carbon content within the ecosystem. This is exemplified by the fact that the number of oribatid mites collected using modified Tullgren funnels was positively correlated with the content of total soil carbon. This group of mites are also useful in the studies of environmental pollution. They are known to specify conditions of radioactive pollution and industrial pollution. *Tectocepheus velatus, Scutovertex sculptus, Protoribates capucinus, Achipteria coleoptrata, Eupelops tardus* and *Pilogalumna allifera* thrive on dolomitic dump. Some other oribatid species like *Oppiella nova, Ceratozetes peritus, Punctoribates punctum* and *Tectocepheus velatus* colonise zinc metallurgic dump.

The modern concept of control of pests and parasites by their natural enemies is gaining momentum day by day. It is in this context

that the unique role played by various predatory species of oribatid, mesostigmatid and phytoseiid groups becomes important. A number of these mites have been identified as excellent predators of insect and mite pests. The phytoseiid predators of cyclamen mite on strawberries offer an excellent example. *Steneotarsonemus spinki,* a serious pest of paddy in Taiwan is successfully controlled by a predatory ascid mite, *Lasioseius paraberlesei,* Pyemotid mites act as good control agents for the imported red fire ants. Works are in progress examining the efficiency of *Cheyletus cocos* in the biological control of the coconut mite, *Aceria guerreronis.* The population density of the common housefly which transmits many contagious diseases, can be kept under control using certain ground dwelling species of mites like *Macrocheles muscadomesticae* which is known to feed on its eggs. Studies conducted on the feeding habits of oribatid species belonging to the genera *Galumna* and *Scheloribates* through laboratory and gut content analysis have established their role as predators of soil nematodes, especially the plant parasitic forms. *Pergalumna omniphagus* exhibits definite preference towards live nematodes. Members of *Scheloribates* and *Xylobates* have been found sucking body fluids of earthworms causing their death. Another instance of a species of *Oppia* from Silent Valley has been found predating on nematodes. *Scheloribates laevigatus* is

observed to feed on pupae of parasitic Hymenoptera. These feeding activities of mites can be suitably exploited to improve our agricultural practices.

Eradication of weed plants is now a global problem for which successful solution is yet to be derived. Many of our agricultural fields, fresh water bodies and inland water systems are clogged and choked by the extensive growth of the common waterhyacinth, *Eichhornia crassipes*. This poses severe threat to agriculture, fisheries and water transport besides causing environmental hazards like water pollution, mosquito problems and hindrance to human recreation like swimming, boating etc. A major portion of the Ootty lake, a hot spot of tourist attraction in Southern India and Veli Kayal in Trivandrum are rendered inaccessible due to the spreading of this weed. A sizeable amount of money is being spent by many countries to check the growth of such plants and to prevent spreading of the same to unaffected areas. The problem becomes more severe by the increased biological oxygen demand and release of hydrogen sulphide due to their decomposition, causing damage to turbine equipment in power stations and giving protection to some snails which act as intermediate hosts of liver flukes like *Bilharzia sp.*

It is in this context that the potential of an oribatid mite, *Orthogalumna terebrantis* to exert an effective control of this weed plant assumes international importance. Active feeding by this mite produce galleries on the upper surface of the leaves which result in yellowing of the leaves followed by death of the plant. Another oribatid species viz., *Punctoribates longiporosus* is also an effective control agent of this plant. *Chromolaena odorata* is a terrestrial equivalent of *Eichhornia crassipes.* About twenty species of oribatid mites have been found inhabiting the receptacles and crinkled leaves of *C. odorata,* of which *S. decarinatus* appears to be impressive.

Apart from all the above mentioned beneficial and harmful activities, mites can be viewed from a totally different view point. Those with a good aesthetic sense will never fail to appreciate the beautiful coloured skins of trombiculid mites. The irridescent hues of the shiny scutes of ticks are always a cynosure to many. The heavily ornamented epidermis of lohmanniid mites is marvellously beautiful. The pearly chain of tubercles forming the notogastral bands, the beautifully arranged area porosae, the long branching sensillus emerging out of the bothridial cup etc. add to the perfection of these mites. The rows of moulting skin with its merging colours carried on the back of members of Basilobelbidae give it the appearance of an

opera dancer. A galumnoid mite, graciously moving with its expanded pteromorph is a magnificent sight. Phthiracarid and mesoplophorid mites with their ability to roll into a ball when disturbed remind us that each and every organism has its own special protective adaptation afforded by nature. Thus the innumerable diversity of the mite fauna give us a chance to appreciate the minute spectra of magnificence exhibited by these little things of beauty.

From the above account it appears that, oribatid mites stand out significantly from others due to their positive and negative roles on man and his environment. A closer scrutiny shows that their role in the biodegradation of organic litter surpass all other beneficial activities due to their sheer abundance and species diversity in soil ecosystem. The importance of oribatid mites in the natural ecosystem has been stressed by many investigators. Every year, large quantities of litter get accumulated on the surface of the earth. These plant materials become an integral part of soil ecosystem only after an effective involvement of microbes and other micro-arthropods, especially mites. Thus, they act as excellent bio-degraders of plant and other organic matter in the soil. This process makes the soil organically rich with increased fertility and hence agricultural productivity.

The role of oribatid mites in the transformation of energy from one trophic level to the next makes it available to a new set of crop plants. This indeed is a promising aspect to be exploited specifically by countries with an economy based on agriculture. Our country mainly depends on agriculture to harness money for developmental purposes. It is here that we should recognise and utilize the potentialities of oribatid mites in the promotion of soil fertility and productivity. This can be done only if we have adequate knowledge about the various groups of oribatid mites which have a role in biodegradation. Hence it is thought highly essential to carry out a study to exploit the biodegradative potential of these mites so that their utilization for human welfare can be envisaged.

Considering the above facts, the present topic of research was charted out to get a general understanding of the oribatid mites along the following lines:

1. To make a survey of oribatid fauna inhabiting totally unrelated ecological set ups to identify major taxonomic groups of oribatid mites involved in biodegradation.
2. To study the impact of the major environmental factors like temperature and rainfall on species density and diversity of

oribatid mites.

3. To determine the feeding potential of oribatid mites.
4. To study the reproductive behaviour of selected oribatid members with a role in bioprocessing of organic litter.
5. To quantify the efficacy of oribatid feeding in enriching soil fertility and productivity through chemical analysis.
6. To prove experimentally the above fact through 'Oriculture Technology'.

PART I
REVIEW OF LITERATURE

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

REVIEW OF LITERATURE

Scientific study on any organism starts with an analysis of its taxonomic position. For considering the various roles played by oribatid mites in natural ecosystem, a thorough knowledge on their taxonomy is of great significance. Taxonomic studies of oribatid mites have witnessed considerable progress during the recent years resulting in the addition of hundreds of new taxa all over the world. Consolidation of all these information, though not possible due to limitations of space, an attempt is made here to incorporate most of the relevant literature on taxonomy of oribatid mites.

Pearse (1906) was the pioneer in the study of oribatid fauna of Indian subcontinent. He recorded twenty species of these mites along with a new genus *Chaunoproctus* from Sikkim. New records of oribatid species from New Zealand were made by Michael (1908). Ewing (1909) surveyed the oribatid fauna of America and recorded several new species. The same author conducted a survey on oribatid fauna of Nilgiris during the next year (1910). Warburton (1912) carried out a survey on oribatid fauna of Seychelles. Ewing (1917) brought forth a synopsis of oribatid mites of North America. The same author (1918) provided data on the oribatid fauna of Mary's park, Oregon.

Sellnick (1925) carried out a survey on the oribatid fauna of Sumatra. Jacot (1929) gave a detailed description of the oribatid genus *Neoliodes*. The same author (1933) described two species of galumnoid

mites, *Galumna tesselata* and *G. nilgiria* from Nilgiris. A survey on phthiracarid mites of North Eastern United States was carried out by Jacot ((1938). A new species of *Scheloribates, S. chauhani* was described by Baker (1945). Hammer (1953) investigated the oribatid fauna of Queensland and reported a new species. Grandjean's (1954) classification of oribatid mites is a classical work in oribatid taxonomy. Hammer (1955) reported a new species of oribatid mite, *Archegozetes magna* from Dutch New Guinea. Wallwork (1957) studied the oribatid mites of a Hemlock - Yellow birch forest. Balogh (1958) conducted a survey on the oribatid fauna of African soils. Aoki (1958a) studied the oribatid mites of Japan and reported a few species of the family Carabodidae. He (1958b) described a new species of the genus *Heminothrus.* The same author (1958c) reported two new species of phthiracarid mites, viz., *Phthiracarus japonicus* and *Steganacarus senex* from Japan. Hammer (1958) conducted studies on the oribatid fauna of Andes mountains. Two new genera of oribatid mites, *Nippobodes* and *Lasiobelba* were added by Aoki (1959). Balogh (1959) presented a survey of oribatid mites of Eastern Africa. Oribatid mites from Polynesia were studied by Sellnick (1959). A new genus of oribatid mite, viz., *Hammation* was erected by Grandjean (1959) with *H. sollertius* as type species.

Balogh (1960) conducted a survey on the cryptostigmatid mites of Congo. Aoki (1961a, b, c) reported several new species of oribatid mites from Japan. Balogh (1961) provided an outline for classifying oribatid mites. Csizar (1961) recorded new taxa of oribatid mites from Indonesia.

Wallwork (1961a, b) surveyed oribatid fauna of Ghana and described a new genus. Oribatid mites from Chile were studied by Hammer (1962) who reported several new species. Hartenstein (1962a, c, d) carried out taxonomic and biological studies of three species viz., *Belba kingi, Ceratozetes gracilis* and *Platynothrus peltifer.* Wallwork (1962a, b) studied taxonomy and distribution of oribatid fauna of Ghana. Balogh (1962a) reported new species of Lohmanniidae from Peru. He (1962b) also reported a new taxon from Madagascar. Piffl (1963) described a new species of *Heptacarus, H. notoneotrichus* from Egypt. Ten species and three new genera of oribatid mites from Angola and Congo were reported by Balogh (1963). Woolley and Higgins (1963) gave illustrated descriptions of new species of *Eremulus.* Four new species of oribatid mites were described by Aoki (1963) from Japan. The same author (1964a, b) also studied the oribatid fauna of Laysan island and New Guinea.

Two new genera, *Sadocepheus* and *Oscesobates* were erected by Aoki (1965a) while studying oribatid mites from Japan. The same author (1965b) described two new species of *Hermanniella,* viz., *H. punctulata* and *H. coristota.* Further, he (1965c) made a revision of the family Otocepheidae along with a description of twelve new species. He (1965d) conducted a survey of oribatid fauna of Himalayas and reported four new species. Another survey conducted in Thailand by the same author (1965e) yielded six new genera and several new species and subspecies of oribatid mites. The author (1965f) also described a new subspecies viz., *Epilohmannia pallida pacifica* from Hawaiian islands. A

new species of galumnoid mite, *Orthogalumna terebrantis* was found tunnelling the leaf tissues of the aquatic weed *Eichhornia crassipes* reported by Wallwork (1965) from Uruguay. Prasad (1965) gave details of three species of oribatid mites from Bhagalpur in India. Grandjean (1965) added four new taxa of oribatid mites. Balogh (1965) provided a synopsis of world genera of oribatid mites.

Piffl (1966) described a new species of lohmanniid mite, *Heptacarus supertrichus* from Iraq. Aoki (1966a) gave details of a new species of oribatid mite *Trichthonius simplex*. He (1966b) erected a new family based on the type species, *Tokunocepheus mizusawai*. The same author (1966c) described three new species and a new subspecies of galumnoid mites from Japan. Further, he (1966d) reported another new species, *Malaconothrus japonicus* inhabiting birds' nests from central Japan. A new species, *Podoribates cuspidatus* from pasture soils of Japan was described by Sakakibara and Aoki (1966). Hammer (1966) described several new species of oribatid mites from New Zealand. A survey conducted by Karppinen (1966) in central Africa helped him to erect a new genus and six new species of oribatid mites. Two new oriatid species were reported by Higgins (1966) from South America. Studies conducted by Balogh and Mahunka (1966) helped to establish several new taxa of oribatid mites from South Africa.

Aoki (1967a) erected a new genus, *Rhabdoribates* and described two new species and a new subspecies. The same author (1967b) reported a new species in the genus *Sphodrocepheus*. Aoki (1967c) revised the family Otocepheidae and erected a new subfamily Tetracondylinae.

He (1967d) also reported two new species of *Liacarus* and one new species of *Xenillus*. Oribatid mites from Vietnam were studied by Balogh and Mahunka (1967) who reported twenty four new species. Systematic position, distribution and habitat of four species of lohamanniid mites were studied by Perez Inigo (1967). Hammer (1967) carried out a survey on the oribatid fauna of New Zealand and reported several new taxa. Balogh and Mahunka (1968a) provided data on four new genera and eighteen new species of oribatid mites from South America. In another study, the same authors (1968b) erected four new species from Indonesia. A new genus, *Nemacepheus* was erected by Aoki (1968a) from Japan with *N. dentatus* as type species. The same author (1968b) while studying free living mites of subalpine forest reported a new genus and thirty five species of oribatid mites

A new species of the genus *Oppia* viz., *O. coloradensis* was reported by Woolley (1969) from dust samples collected from Colorado. Information on the zoogeography of cryptostigmatid mites in Antarctica was provided by Wallwork (1969). Grandjean (1969) classified the suborder Oribatida into six major groups. Fujikawa and Aoki (1969) described two species under the genus *Perlohmannia*. Balogh and Mahunka (1969a) created a new family Xenolohmanniidae and six new species. Further, the same authors (1969b) erected a new family, SternOppiidae, fifteen new genera and fifty six new species of oribatid mites. Aoki (1969) described a new subspecies of the euphthiracarid mite, viz., *Protoribotritia aberrance ensifer* from Japan.

Aoki and Suzuki (1970) added a new species to the genus *Pedrocortesella*. The new genus *Cosmohermannia* was erected by Aoki and Yoshida (1970) from Japan. Aoki (1970a) described a new oribatid mite *Oribatula sakamori* from melon fruits. A new subgenus and seven new species of oribatid mites were collected by the same author (1970b) from living trees from the mountain of Japan. A new genus, *Costeremaeus* from the island of Tsushima was erected by the above author (1970c). He (1970d) also described another new genus, a new subgenus and seven new species of oribatid mites from Japan. Balogh (1970a) conducted a survey on oribatid fauna of New Guinea, and provided illustrated descriptions of one family, thirteen new genera, fifty two new species and one new subspecies. During his Hungarian Soil Zoological Expedition, Balogh (1970b) collected information on seven new genera and forty three new species of oribatid mites. Suzuki and Aoki (1970) reported a new species of galumnoid mite, *Galumnella nipponica* from Izu Peninsula, Japan. Two new species of the family Xenillidae were reported by Woolley (1970) from Lebanon. Feider *et al.*, (1970) erected a new genus, *Romanobates* and three new species belonging to the family Oribatulidae.

Aoki and Fujikawa (1971) provided illustrated account of a new species of *Allodamaeus* viz., *A. adpressus*. Krivolutski (1971a) explored the oribatid fauna of central Asia which helped him to recover three new genera viz., *Asiacarus, Arenozetes* and *Mystroppia* He (1971b) continued his work in Kirgisia which yielded six new species of oribatid mites belonging to six genera. A catalogue and bibliography of acari of New

Zealand was presented by Spain and Luxton (1971). Hammer (1971) collected eighty three species which included eight new genera and forty three new species. Kardar (1972) described a new species of Indian lohmanniid mite, *Papillacarus indicus*. A key for the identification of oribatid mites of Hokkaido was provided by Balogh (1972). Fujikawa's (1972) report contained the list of one hundred and six species of oribatid mites belonging to seventy six genera and forty seven families. Hammer (1972) could identify sixty species of oribatids including four new genera, thirty six new species and five new varieties from Tahiti and the Atoll of Rangiroa.

Studies conducted by Aoki (1973) on oribatid fauna of Southern Japan yielded one new genus, six new species and a new subspecies. A new subspecies and several new records of oribatid mites were reported by Chakrabarti *et al.*, (1973) from India. Mahunka (1973) could collect several new oribatid taxa from Rhodesia. Kardar (1974) added a new species of the genus *Tectocepheus* to the list of Indian oribatid fauna. A new species of the genus *Basilobelba* viz., *B. indica* was described by Bhaduri *et al.*, (1974). Bhattacharya *et al.*, (1974) collected data on three new species and one new subspecies of lohmanniid mites from Santiniketan in West Bengal. Chinone's (1974) contributions enriched our knowledge on the family Brachychthoniidae through his description of six new species, two new subspecies and a few new records of oribatid mites. Balogh and Mahunka (1974) provided a better understanding of the oribatid fauna of Malaysia by furnishing illustrations of a number of new taxa. Classification of oribatid mites

from India was made easier by the key to the superfamilites provided by Prasad (1974). Two new species and a subspecies of oribatid mites from Hokkaido, Japan was described by Aoki and Ohnishi (1974).

Metz and Sharma (1975) added a new species, *Oppia durhamensis* to the family Oppiidae. Seniczak (1975) revised the above family based on the morphology of juvenile stages of its members. Oribatid fauna of central Sahara was surveyed by Hammer (1975). Two new species of *Oribatella* from India were reported by Kardar (1975). Bhaduri *et al.*, (1975) presented descriptions of two new species of *Chaunoproctus* from India. Works conducted by Biswas and Bhaduri (1976) helped to add three new species to the genus *Scheloribates* from West Bengal. Deb (1976) collected a new species of *Rhysotritia* from the above locality. Four new species each were added to the genera *Oppia* and *Scheloribates* respectively by Kardar (1976a, b). While studying the oribatid fauna of Hong Kong, Mahunka (1976) described five new species.

Van Der Hammen (1977 a, b, c, d) in a series of papers provided a collective summary of the taxonomic works of Berlese. Norton (1977) described the family Damaeidae while reviewing Grandjean's system of leg chaetotaxy. Oribatid fauna associated with moss in central Spain was studied by Perez-Inigo (1977). Balogh and Mahunka (1977) reported eleven new oribatid species from Neogea. Chakrabarti *et al.*, (1977 a, b) provided data on a new species of *Haplochthonius* and two new species of *Nanhermannia*.

Haq (1978a) reported 12 species representing six families and eleven genera belonging to Oribatei Inferiores and thirteen species

representing Oribatei Superiores from Kreala, India. Bernini (1978) reported two new species of *Oribatella* from Italy. Oribatid fauna of Neogea was studied in detail by Balogh and Mahunka (1978). Chakarabarti *et al.*, (1978) furnished data on two new species of *Pseudotocepheus* from West Bengal. Investigation carried out by Gjelstrup (1978) led to the recovery of twenty seven species of oribatid mites associated with moss and lichen from Faroe islands. In a series of papers, Mahunka (1978a, b, c) gave details of his exploration on oribatid fauna of Seychelles in Mauritius and Dominican republic. Aoki (1978) conducted a survey of the family Carabodidae and established a new genus, three new species and one new subspecies.

A new genus, *Pseudocryptacarus* belonging to the family Lohmanniidae was collected by McDaniel *et al.*, (1979) from the Gulf coastal regions of South Texas. Haq (1979a) reported a new species, *Xiphobelba ismalia* from India. Ghosh and Bhaduri (1979) while conducting a study of oribatid mites of Nagaland reported two new species, viz., *Eremobelba indica* and *Allonothrus monensis*. Corpuz Raros (1979a) prepared a preliminary list of oribatid mites of Philippines which included one hundred and fifty three species. She (1979b) also provided information on Philippine lohmanniid mites. Chakrabarti *et al.*, (1979a) published a list of twelve oribatid mites which they collected from Darjeeling. A new genus *Sigmonothrus* from West Bengal was erected by Chakrabarti *et al.*, (1979b). Chakrabarti and Talukdar (1979) collected oribatid mites from Assam and reported a new species of *Malaconothrus*. Bhattacharya and Banerjee (1979) described a new

species, *Pilobatella berlesei* from North India. Balogh and Mahunka (1979) modified the system of classifying primitive oribatids by incorporating new taxa in the family Phthiracaridae, Protoplophoridae and Epilohmannidae. Parry (1979) made a revision of the British species of the genus *Phthiracarus*. The second species of the genus *Epilohmannoides* was erected by Okhubo (1979) with his description of *E. esculatus* from Japan.

Aoki (1980) revised the family Euphtiracaridae and added a new species of the genus *Euphthiracarus* from Japan. Work conducted by Corpuz Raros (1980) provided more information on the family Basilobelbidae from Philippines with the addition of five new species. Balogh and Mahunka (1980) studied Neogean oribatid mites and provided illustrated description of thirty four species of oribatid mites from Italy. A survey on oribatid mites of Sikkim, Himalaya was conducted by Dhalli *et al.*, (1980) who described two new species of *Scheloribates* and one new species of *Chaunoproctus*. Investigations on oribatid fauna of Poland conducted by Neidbala (1980) resulted in the recovery of two new species of Phthiracaridae. Norton and Metz (1980) erected a new oribatid family, Neohyphochthoniidae based on the species *Neohypochthonius porosus* which they described. Norton's (1980) studies on North American oribatids, led to the discovery of three new genera, *Caenobelba, Lanibelba* and *Quatrobelba*. Okhubo (1980) described a new species, *Brachyoripoda punctata* from Japan.

Corpuz-Raroz (1981) added seven new species to the genus *Peloribates* as a result of survey on Philippine oribatid mites.

Bhattacharya and Banerjee (1981) described a new species of *Neoppia* from Santhiniketan, India. Bhaduri and Raychaudhuri (1981) reviewed taxonomy and distribution of oribatid mites in India. Raju *et al.,* (1981) introduced a new species to the genus *Pergalumna* viz., *P. andhraensis.* Sanyal and Bhaduri (1981) recovered a new species from Bengal, *Hoplophorella sunderbanensis.* Trave (1981) reported a new species of Indian oribatid, *Vaghia blascoi* from soils of Palani Hills. Neidbala (1981) studied phthiracarid mites from South America and described a new species, *S. absimillus.* Balogh and Mahunka (1981) established two new genera, twenty seven new species and five new subspecies based on the specimens collected from Neogea. A new species of *Dolicheremaeus* from India was reported by Chakrabarti *et al.,* Hammer (1981) erected a new genus *Spinotocepheus* with four new species from Java.

Asperemaeus was erected as a new genus by Behan (1982) from the collections made from the subalpine habitats of Soviet far east. A new species of *Porogalumnella, P. setosa* was reported by Balakrishnan and Haq (1982). A new genus of oribatid mite, viz., *Pelokylla* with *P. malabarica* as type species was erected by Clement and Haq (1982). Mahunka (1982a) conducted a survey on oribatid fauna of Costa Rica and reported a new genus, *Phthiracarica* and seven new species. In another study conducted by the same author (1982b) in the Eastern Ethiopian region revealed five new genera and thirty two new species. Misra *et al.,* (1982) carried out a survey on phthiracarid mites of North India and erected a new species, *Hoplophorella manipuriensis.* Mondal and Chakrabarti (1982) reported a new species of *Oppia* along with

several new records from the tea garden in Darjeeling. A new species of *Malacoangelia* was reported by Sarkar and Subias (1982) from North India. Sengbusch (1982a, b) carried out a survey on oribatid fauna of Micronesia which yielded a new species under the genera *Haplacarus* and *Javacarus* of the family Lohmanniidae. Neidbala (1982a) provided illustrated descriptions of five new species of phthiracarid mites from Central America and added (1982b) three new species of *Hoplophorella* from Kenya. He (1982c) continued his work on phthiracarid mites which resulted in the description of the new species *Hoplophthiracarus concinuns* and the record of *Phthiracarus clemens* and *P. robertis* from Nepal.

Haq *et al.,* (1983) described a new species and a new subspecies of lohmanniid mites viz., *Haplacarus keralensis* and *Lepidacarus ornatissimus rehmabia* collected from Kerala. Balogh and Balogh (1983a) studied the oribatid fauna of Australia which helped them to erect a new family, Platyameridae with three new genera and twelve new species. The same authors (1983b) recorded a new subfamily, four new genera and seventeen new species of oribatids from the Pacific. Balogh and Mahunka (1983) prepared a catalogue of primitive oribatids of the Palaearctic region. Several new taxa of oribatids from Bali, Indonesia were described by Hammer (1983). Niedbala (1983 a, b, c, d, e,) in a series of papers provided illustrated descriptions of twenty two new species of phthiracarid mites from Uganda and USSR. Sanyal and Bhaduri (1983) described a new species of *Trichthonius* from India. Mahunka (1983) conducted a survey of oribatids of Eastern Ethiopian region which yielded a new genus *Separatoppia* and six new species.

Surveys conducted by Aoki (1984) in Amami Dhshima island of Japan yielded a new genus, *Defectamaerus*, twenty new species and two new subspecies. Sengbusch (1984a, b) described two new lohmanniid mites, *Lohmannia pinnigera* and *Annectacarus granditrichosus* from Micronesia. Ramani and Haq (1984a) studied oribatid mites associated with *Eupatorium odoratum*. In another report, the same authors (1984b) provided an annotated list of oribatid species living in assocation with economically important plants. Neidbala (1984) described four new species of phthiracarid mites belonging to three genera from India. Mahunka (1984) investigated oribatid mites of Paraguay and reported a new genus and twenty three new species.

Luxton (1985), reviewed oribatid mites of New Zealand, incorporating three hundred and sixty six species belonging to one hundred and sixty genera and fifty eight families. Sarkar (1985) recovered a new species of *Archegozetes* viz., *A. tuberculatus* from Tripura. Mahunka (1985) established five new genera and twenty five new species of African oribatid mites. Aoki and Honda (1985) collected a new species of *Austrachipteria*, *A. pulla* form moss samples in Japan. Neidbala (1985) divided the genus *Mesoplophora* into two subgenera viz. *Mesoplophora* s. str. and *Paraplophora* subgen. nov. and added three new species with redescription of other species. Balogh Jr. (1985a) established five new genera and nine new species from Australia. The same author (1985b) discussed the taxonomic status of the genera *Phereliodes*, *Pedrocortesia* and *Pedrocortesella* from Australia with descriptions of five new species. As a result of a survey on the oribatid mites of Hawaiian

islands conducted by the above author (1985c), one genus, four new species and one subspecies belonging to the superfamily Oribatuloidea were erected. Further, he (1985d) provided data on four species of the genus *Phyllhermannia* including a new species, *P. forsteri* from New Zealand. Balogh (1985e) established a new genus, *Galapagacarus* with *G. schatzi* as the type species from Galapagos islands. Information on distribution of *Ceratozetes gracilis* in Arctic area of Western North America was provided by Behan (1985). Subias and Rodriguez (1985) with the help of oribatid mites collected from Spain redefined the subfamily Mystroppinae and described two new subgenera, *Karamella* (*Stakerenoppia*) and *K.* (*Glabroppia*).

Balogh and Balogh (1986a) collected two new genera and twenty two new species from forest ecosystems of New Guinea. The same authors (1986b) in a discussion on the distribution of oribatid mites in Western Pacific region, described six new species and one new subspecies. Aoki (1986a) added a new species to the genus *Cepheus, C. kursawai* from Yonizawa in Japan. The same author (1986b) collected two new species of the genus *Fissicepheus* from South West Japan. Niedbala (1986a) described a new species of *Hoplophthiracarus, H. inelegans* from Costa Rica. The same author (1986b) brought forth a catalogue of the superfamily Phthiracaroidea and added four new species from Poland, USA and Indonesia. Mahunka (1986a) surveyed the oribatid family Carabodidae and redescribed several species along with a key to the genera. Fujikava (1986) recorded fourteen oribatid species including two new subspecies from nature farm in Nayoro. Mahunka (1986b)

described six new genera and fourteen new species from the republic of South Africa and Tanzania. Niedbala (1986 c) studied the systematics of Phthiracaroidea based as their morphology and evolutionary status of two hundred species of this super family and divided it into two families, three subfamilies, five tribes, one genus and four subgenera along with a key to the identification of the taxa. Balogh (1986a) provided a key for identification of the species group of *Xenillus ornatus*, adding four new species from Neotropical region. In another paper, the author (1986b) described three new species of *Hamotegaeus* from South America and provided a key to the known species of the genus. The same another (1986 c) added a new species of *Phyllocarabodes*, viz., *P. ormatus* from Columbia and provided a key to the above genus. A new species each were added to the genera *Heptacarus, Oppia* and *Scheloribates* by Bayoumi and Alkhaufa (1986). Choi (1986) described new and unrecorded species of oribatids under the family Oppiidae. Three new species of *Pedrocortesia* were reported from USSR by Ryabinin (1986).

Marshall *et al.*, (1987) brought out a catalogue of oribatid mites of continental United States and Canada. A new species of *Parachipteria* from North Wales was reported by Collof and Seyd (1987). Mahunka (1987) revised the family *Carabodidae* and redescribed the species of *Carabodes* and *Austrocarabodes* adding new species to these genera, and *Odontocepheus* from North and East Africa, Asia and Europe. Karppinen *et al.*, (1987) listed 725 species by conducting a survey on oribatid fauna of Crimea and Caucasus. Norton and Palacios Vargas (1987) added a

new species to the genus *Cryptozetes, C. usnea* along with a description of the immatures of the species. Balogh and Balogh (1987 a) developed identification keys for ptycoid Mixonomata of the Neotropical region. The authors (1987b) also reviewed the family Lohmanniidae including one 140 species and providing keys for their identification. A revision of the superfamily Oppioidea was made by Balogh (1987). The subgenus *Ametroproctus* from Western North Africa was redescribed by Behan (1987), adding four new species and a key to its subgenera.

The first report on the genera *Mesotritia* and *Euphthiracus* from India was made by Sanyal (1988) who described three species, viz., *M. indica, E. meghalayensis* and *Eremobelba shillongensis* from Meghalaya. Sanyal and Bhaduri (1988) provided a list of fifty seven families comprising one hundred and thirty two genera. Balogh and Balogh (1988a) continued their earlier studies on neotropical oribatid fauna and provided 143 plates containing 1018 figures. In another paper, the authors (1988b) gave an account of the family Ceratokalummidae. Mahunka (1988) carried out a survey on oribatid mites of Vietnam and established three new genera, *Kaszabozetes, Subpirnodus* and *Vietoppia* and fifteen new species. A new genus, a sub genus and eleven species of oribatid mites from Sri Lanka were described by Balogh (1988a). An identification key to the genus *Ameroppia* was prepared by the above author (1988b). Wang (1988) reported six families, thirteen genera and twenty nine species of crotonoid mites of China and described a new species of *Allonothrus.* Niedbala (1988a) in a revision of the superfamily Phthiracaroidea synonymised eleven genera of family Phthiracaridae.

The same author (1988b) proposed a new system of classification of Mesoplophoroidea, dividing the superfamily into two familes viz., Mesophophoridae and Apoplophoridae. Sheela and Haq (1988) reported six species of oribatid mites associated with *E. crassipes*, a weed plant.

Grobler (1989) described four new species of the genus *Eupelops* and made a comparison of South African species. Balogh (1989) investigated the oribatid fauna of Ecuador, and erected a new family, Tubutozetidae, a new genus and a new subspecies. Two new species of Damaeidae viz., *Damaeus exspinosus* and *D. costonotus* from China were reported by Wang and Norton (1989). Norton and Olszanowski (1989) added a new species to the genus *Holonothrus, H. virunglensis* from volcanic area of Ethiopia. Mahunka (1989) collected four new species of galumnoid mites, two each belonging to the genera *Galumna* and *Pergalumna* viz., *G. aba, G.khoii, P. kokschyi* and *P. margaritata* from Vietnam. Subias and Balogh (1989) provided a review of world genera of Oppiidae and a systematic catalogue of genera and subgenera.

Sengupta and Sanyal (1990) collected 12 genera and 20 species of oribatid mites from the soils of Himalaya. An identification key of oribatid fauna of Neotropical region was prepared by Balogh and Balogh (1990) with 830 illustrations contained in 142 plates. Mahunka (1990a) analysed the family Phthiracaridae by providing an identification key to the genera and also established a new subgenus. The same author (1990b) made a survey of oribatid mites of Philippines and Indonesia and erected three new species. Oribatid mites inhabiting coconut palms in South India were studied by Ramani and Haq (1990a,

b) who reported two new species viz., *Uracrobates indicus* and *Notogalumna nortoni.*

Neidbala (1991) continued his studies on the superfamily Phthiracaroidea and described the origin, centres of specialisation and rates of evolution of individual genera of these mites in different parts of the world. A redescription of the types preserved in "Berlese Collection" in Florence was made by Mahunka (1991a) who provided supplementary notes supported with figures. The same author (1991b) studied oribatid fauna of East Malaysia and erected two new genera and seven new species. He (1991c) also explored oribatid mites of Cape-verde Islands from where he collected 29 species of oribatids including four new species. From Visayas Islands of Philippines, Corpuz-Raroz (1991) reported twelve families and fifteen genera of oribatid mites, of which five species were new to science. Clement and Haq (1991) described two new species, one each from the genera *Cryptacarus* and *Annectacarus*. Schatz (1991) expressed his ideas about arrival and establishment as well as speciation of oribatid mites on oceanic island of the Galapagos.

Results of a survey conducted by Jaikumar *et. al.* (1992) on oribatid mites associated with coconut palm yielded a total of 21 species belonging to 19 genera and 14 families. Ramani and Haq (1992a) reported a new species of the genus *Afronothrus* viz., *A. arboreus* from Kerala, India. Ramani and Haq (1992b) gave data on global distribution of the various species of *Lohmannia*. Kardar (1992) studied lohmanniid mites in India and reported some new species of *Javacarus*.

Perez-Inigo and Baggio (1993) reported six new species and two new subspecies of oribatid mites from Sao Polo, Brazil. Schatz (1993) found three *Lohmannia* species in the Galapagos islands and described *L. vulcania.* Haq and Jaikumar (1993) described a new species, *Meristacarus degradatus* from Kerala, India. Behan (1993a) studied systematic and ecological problems of oribatid mites in Canada. The same author (1993b) gave an account of oribatid mites of the family Eremaeidae of North America. Phylogenetic perspectives of oribatid mites were discussed by Norton *et. al.,* (1993). Niedbala (1993) provided illustrated accounts of three new species of oribatid mites belonging to the family Euphthiracaroidea from Africa. Nawar and Borolossy (1993) added a new species to the genus *Zygoribatula, Z. grandjeani* from upper Egypt. The authors presented a key to the Egyptian species of the genus.

Jaikumar *et al.,* (1994) reported a new species of lohmanniid mite, *Annectacarus aokii,* from forest area of Western Ghats of Kerala. Behan and Bissett (1994) gave an account of oribatid mites of Canadian peatlands. Monetti *et al.,* (1994) collected a new oribatid mite of the genus *Eremaeozetes, E. araucana* from the arid zones of Argentina.

Haq and Clement (1995) added two new species to the lohmanniid mites by their description of *M. wynadensis* and *H. porosus.* Mahunka (1995) reported two new species of the family Brachychthoniidae from Comoro island, viz., *Liochthonius reductus* and *Sellnickochthonius comorensis.* Block and Convey (1995) described *Alaskozetes antarcticus* as a dominant member of many terrestrial communities in the Antarctic. Martinez and Casanueva (1995) described

and illustrated a new species, *Liochthonius nortoni* from soil samples collected from Chile. Two new species of the genus *Liodes, L. marplatensis* and *L. elongatus* were described from the Argentinean republic by Fernandez *et. al.* (1995) Distribution pattern of *Pergalumna* sp. was discussed by Oppedisano *et al.*(1995), Lebrun and Straalen (1995) examined the prospectus of using oribatid mites in ectotoxicology. Martinez *et. al.* (1995) described a new species *Tenuelamellarea argentinensis* of the family Lamellareidae from soil samples of Argentina.

Starry (1996) conducted a survey of oribatid mites of secondary successional row of brown soil in South Bohemia. Norton *et al.,* (1996) described in detail the aquatic oribatid mite genus *Mucronothrus* wihich they collected from Canada and western U.S.A. Migge *et al.,* (1996) studied on a comparative basis the oribatid fauna associated with spruce and beech. Maraun *et al.,* (1996) gave a report of oribatid mites collected from the soil of a beech forest.

Dinesh *et al.,* (1997) studied population dynamics of oribatid mites in a forest plantation. Haq and Ramani (1997) collected several new species of oribatid mites belonging to various genera and families and described a new species *Lepidacarus prabhooensis.* Ramani and Haq (1997) reported a new species, *Caloppia sejugatus* from coconut palm in Kerala. Oribatid mites from five post industrial dumps were investigated by Skubala (1997) who collected one hundred and eight species. Shtanchaeva (1997) studied the fauna of oribatid mites inhabiting lichens in a pine forest of the Bryansk region, Central Russia. Maraun (1997) gave an account of the semiaquatic genus *Tegeocranellus*

of North and Central America. Alberti and Norton (1997) described with diagrams the porose integumental organs of oribatid mites.

Balogh and Balogh (1998) presented a short review of the family Micreremaeidae with identification keys for four genera and eleven known species of the family. The authors also erected a new genus *Mexiceremus*. Two new species of oribatid mites with report of a new record from Haryana state of India was published by Bose *et al.*, (1998). Collof and Halliday (1998) published the first catalogue of Australian orbatids containing a comparative taxonomic coverage including many new records of species and genera. Franklin *et al.*, (1998) studied populations of arboreal oribatid mites in two inundation forests. Gil Martin and Subias (1998) provided a biogeographic analysis of nine hundred and eighty two species and subspecies of oribatids from West Mediterranean. Thirty nine species of oribatidae in thirteen families inhabiting western coast of the Taimyr Peninsula in Northern Siberia were reported by Grishina *et al.*, (1998). Hunt *et al.*, (1998) brought out an interactive glossary of oribatid mites and an interactive key to oribatid mites of Australia. Maraun *et al.*, (1998c) studied the oribatid mite community of pure and mixed stands of beech and spruce. Ramani and Haq (1998a, 1998b) provided taxonomic descriptions of two new species, viz., *Siculobata malabarica* and *Scapheremaeus nuciferosa* from coconut palms. Schatz (1998) described a total of two hundred and two oribatid species belonging to sixty four families of which eighty one were new to science from the Galapagos islands. Starry and Block (1998) discussed the distribution and biogeography of oribatid mites in Antarctica,

Subantarctic islands and nearby land areas and reported one hundred and five species from twenty families. Weigmann (1998) analysed segmentation in oribatid mites from phylogenetic and ontogenetic point of view.

Badejo *et al.*, (1999) studied oribatid fauna of seven terrestrial environments over a period of five years. Oribatid mite biodiversity in agroecosystem was studied by Behan and Paoletti (1999). Fernandez (1999) reported a new species of oribatid mite from Cordoba province, Argentina viz., *Oripoda benegasi*. Species diversity of soil oribatids in Yanbaru, the northern part of Okinava Honto, was studied by Ito and Aoki (1999). Jain *et al.*, (1999) quantified oribatid fauna inhabiting forest plantations. Species richness, abundance and diversity of oribatid mites in soil and plant litter were investigated by Migliorini and Bernini (1999). Ramani and Haq (1999) privided illustrated taxonomic characters of a new species of oribatid mite, *Zygoribatida keralensis* collected from *Chromolaena odorata*. Skubala (1999) studied colonization of a dolomitic dump by oribatid mites and recovered eighty two species in Poland. Skubala and Ciosk (1999) collected oribatid mites representing thirty two species from old zinc metallurgic dump in Poland.

Bayartogtokh (2000) redescribed ten known species of the oribatid mite genus *Epilohmannia* from Mongolia and described two new species viz., *E. spathuloides* and *E. shtanchaeve* from central Japan. Kuriki (2000) reviewed the ecological aspects of oribatid mites in sphagnum mines. Maraun and Scheu (2000) compiled data on relative abundance of oribatid mites from different sites especially Europe and Germany. Park-

Hong-Hyun and Lee-Joon Ho (2000) conducted community analysis of oribatid mites in Namsam and Kwangriung coniferous forests. Species abundance, biodiversity, distribution and population dynamics within oribatid mite communities were studied by Tian *et al.,* (2000). Schuster *et al.,* (2000) isolated six species of adult oribatid mites belonging to superfamilies Galumnoidea and Ceratozetoidea from a lawn at Ondersteport in South Africa. Horwood and Butt (2000) studied changes within oribatid mite communities associated with Scots pine regeneration.

Maraun (2001) conducted a study on evolutionary and phylogenetic implications of sexual and unisexual oribatid mites. The same author (2001a) gave a report of sexual and parthenogenetic oribatid mites. Haq (2001) studies oribatid mite strategies in relation to environment. Croft and Jung (2002) conducted stability analysis of soil oribatid mite community from Namsand and Kwangreung deciduous forest in Korea. Battigelli and Berch (2002) reported about short term changes in oribatid mite abundance. Dufrene (2002) described oribatid mite communities from high Shaba in Zaire. Haq and Ramani (2003) described the various methods for sampling and extraction of oribatid mites. The authors also gave a key to the identification of oribatid mites.

PART I
MORPHOLOGY OF ORIBATID MITES

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

MORPHOLOGY OF ORIBATID MITES TERMINOLOGICAL SURVEY

Mites coming under the suborder Oribatida are better known as moss mites or beetle mites. The group exhibits extreme diversity with respect to their morphological features. Hence, a thorough understanding of the terminology used in the study of the identifying characters of oribatid mites is found mandatory. Accordingly, the forthcoming discussion is intended to provide a general treatment of the morphological terms used in the current study of oribatid mites. The pattern of terminology followed here is based on Balogh (1972), Wallwork (1965), Balogh and Mahunka (1983) and Woolley (1988).

The oribatid mites possess a heavily sclerotised body ranging in size from 100 to 1000μm in length. There is hardly any sexual dimorphism. Generally, the body is dorsoventrally flattened, but sometimes cylindrical or with a convex dorsal surface. A thin and hard cuticle forms a uniform covering for the body, which becomes sclerotised to different degrees among individual species.

The body of any oribatid mites can be easily divided into two parts (1) an anterior propodosoma or proterosoma or prosoma covered with a dorsal shield called prodorsum and (2) a posterior hysterosoma or opisthosoma covered with the dorsal shield called notogaster. The dorsosejugal suture separates the prodorsum from the notogaster which may sometimes be interrupted or even absent in some cases. The

proterosoma represents the anterior part of the original prosoma while hysterosoma is a composite structure formed of posterior part of prosoma bearing legs III and IV and the original opisthosoma. The region carrying legs I and II is designated as propodosoma while legs III and IV are carried by metapodosoma. The propodosoma along with metapodosoma form the podosoma.

Prodorsum (Plate-1, Fig. 1)

The cuticular shield covering the dorsal and dorsolateral regions of the proterosoma is designated as the prodorsum. It is referred to as the aspis (Plate-2, Fig. 2) in cases where the lateral region of the proterosoma remains thin and unsclerotised. In lower oribatids the proterosoma can be folded below the hysetrosoma like the blade of a pen knife. Higher oribatids lack this capacity, but is either slightly movable or firmly attached to hysterosoma. The prodorsum generally has a triangular outline and its extreme anterior end is referred to as the rostrum. Prodorsum bears 4-6 pairs of setae at definite positions and they are 1. sensillus (*ss*) or pseudostigmatic organ 2. Interlamellar seta (*in*) 3. lamellar seta (*le*) 4. rostral seta (*ro*) 5. anterior exostigmatal or exobothridial seta (*exa*) and 6. posterior exostigmatal or exobothridial seta (*exp*). Higher oribatids possess only a single pair of exostigmatal seta resulting in five pairs of prodorsal setae or some times both the exostigmatal setae may be absent bringing the number down to four pairs. Each sensillus emerges from a cup shaped invagination called bothridium (*bo*) or pseudostigmata. Sensillus is the characteristic sense

organ present in majority of oribatid mites, but may be very small or even absent in some members. It takes a variety of forms in different individuals and are named accordingly as setiform, fusiform, lamelliform, clavate, pectinate, spathulate etc.

The rostral setae originate just below or above the rostral tectum. Lamellar setae are seen near the lamellar apex or lamellar cuspis. Interlamellar setae arise from the inter-bothridial region between the lamellar base or they may be located close to the dorsosejugal suture. The anterior and posterior exobothridial setae originate from the anterior and posterior sides of bothridium respectively. The nature of these setae varies from one species to the next.

From the base of the bothridium extends an outgrowth reaching upto the rostrum, which runs a little away from the lateral margin of the prodorsum. If this structure is flat or plate like, then it is called lamella. But sometimes it is just a rib-like structure projecting slightly above the level of prodorsum and is called costula. The lamellae of both sides are quite often connected by translamella. The tip of the lamella is called the cuspis. The surface of the prodorsum is marked by reticulations and punctations of varying size and shape, characteristic of each species.

Notogaster (Plate-1, Fig. 1)

It represents the cuticular shield covering the dorsal part of hysterosoma and lies posterior to the prodorsum. The shape of the notogaster is highly variable among different species, it may be elongated, round, oval, globular, pentagonal or hexagonal, sometimes

becoming broader towards the posterior end. Usually notogaster is entire but sometimes divided into 2-4 parts by 1-3 transverse sutures. Notogaster is formed of six segments in primitive oribatids arranged in the order *c, d, e, f, h* and *ps* from anterior to posterior end. These segments carry setae in definite arrangements, the number of which vary in lower and higher oribatids. The fundamental number is 16 pairs which is seen in primtive oribatids, but it may be reduced up to 10 pairs in higher oribatids. Grandjean (1954) has applied a special system of chaetotaxy to refer to the notogastral setae. While naming seta, it is customary to name the segment first followed by a number indicating the relative position of the seta, from the mid-dorsal region towards the lateral side.

Notogstral setal notations

1. The notation for primitive oribatids with 16 pairs of setae:

First row	: c_1, c_2, c_3
Second row	: d_1, d_2, d_3
Third row	: e_1, e_2
Fifth row	: h_1, h_2, h_3
Sixth row	: ps_1, ps_2, ps_3

2. The notation for higher oribatids with 14 or 15 pairs of setae:

Here the first and last two rows are homologous to those of primitive oribatids and hence the same notation is applied. But the homology of the middle six pairs of setae is doubtful and are named according to their relative positions into three transverse rows as follows:

First row	: c_1, c_2, c_3
Second row	: *da*, *la*
Third row	: *dm*, *lm*
Fourth row	: *dp*, *lp*
Fifth row	: h_1, h_2, h_3
Sixth row	: ps_1, ps_2, ps_3

Here *d* stands for dorsal, *l* lateral, *a* anterior, *m* median, and *p* posterior.

3. Notations for higher oribatids with 10 pairs of setae:

Here there are only four rows of setae and the rows are named as *t*, *ms*, *r*, and *p*. Setae in the first row are indicated by three small letters of the alphabet viz., *a*, *e* and *i*. Second row has only one seta which is named as *ms*. The last two rows have three setae each and named as *p* using serial numbers 1, 2 and 3 as follows:

First row	: *ta*, *te*, *ti*
Second row	: *ms*
Third row	: r_1, r_2, r_3
Fourth row	: p_1, p_2, p_3

Here *a* means anterior, *e* exterior and *i* interior. Some primitive oribatids have more than 16 pairs of setae. They are different from the normal ones and are called neotrichial setae and the condition is known as neotrichy.

Different types of setae

Setae in oribatid mites are highly varied and appear in greatly specialised forms. The following types of setae have been recognised in

the various oribatid mites considered in the present study (Mahunka and Zomberi, 1985).

1. Flagelliform (Plate-3, Fig. 1): Irregularly bending, slender like a thread, resembling a whip eg:- *Megalotocepheus glabrus* sp. nov.
2. Setiform (Plate-3, Fig. 2): Slender gradually tapering apically, bristle-like eg: *M. glabrus* sp. nov, *Papillacarus elongatus* sp. nov., *Annectacarus malabaricus* sp. nov and *Javacarus minutus* sp. nov.
3. Spiniform (Plate-3, Fig. 3): Broad based, gradually tapering apically, resembling a spine or thorn. Eg:- *Phthiracarus haqi* sp. nov.
4. Clavate (Plate-3, Fig. 4): Petiolate basally, thickened towards the end, club-shaped eg: *Atropacarus (Hoplophorella) reticulatus* sp. nov.
5. Foliate (Plate-3, Fig. 5): Slightly broad based, broadest in the middle, gradually tapering to a point. Eg: *J. minutus* sp. nov.
6. Arboriform (Plate-3, Fig. 6): With branches arising from the base eg: *Vepracarus arboriformes* sp. nov.

Setae may be provided with special types of ornamentations as follows:

1. Pectinate (Plate-3, Fig. 7): Unilaterally beset with hairs or bristles arranged so as to resemble a comb. Eg: *Vepracarus ramaniae* sp. nov.
2. Ciliate (Plate-3, Fig. 8): Irregularly beset with fine hairs eg: *P. elongatus* sp. nov.
3. Pennate (Plate-3, Fig. 9): Bilaterally densely fringed with long fine hairs resembling a feather. Eg: *A. malabaricus* sp. nov., *Heptacarus indicus* sp. nov.

4. Brocate (Plate-3, Fig. 10): With very fine bristles towards the tip. Eg: *Atropacarus (Hoplophorella) chaliensis* sp. nov.

Margins of setae can exhibit variations as described below:

1. Entire (Plate-3, Fig. 11): With an even margin, without any kind of indentation. Eg: *Haplacarus davisi* sp. nov., *M. glabrus* sp. nov., *J. minutus* sp. nov.
2. Serrate (Plate-3, Fig. 12): Regularly notched like a saw. Eg: *H. xavieri* sp. nov.
3. Barbed (Plate-3, Fig. 13): Densely covered with short bristles, like a stubbly, unshaven face eg: *A malabaricus* sp. nov.
4. Ciliate (Plate-3, Fig. 14): Provided with fine cilia eg: *P. elongatus* sp. nov.
5. Spinose (Plate-3, Fig. 15): Having spine like projections. *H. indicus* sp. nov.

Apices and endings of setae exhibit great variations as described below:

1. Acuminate (Plate-4, Fig. 1): Strongly tapering to a point. *H. indicus* sp. nov., *A. malabaricus* sp. nov.
2. Acute (Plate-4, Fig. 2): Having a sharp point. *H. indicus* sp. nov., *P. elongates* sp. nov., *V ramaniae* sp. nov., *H. xavieri* sp. nov., *H. davisi* sp. nov., *P. haqi* sp. nov., *Annectacarus plumosus* sp. nov., *A. malabaricus* sp. nov., *M. glabrus* sp. nov.
3. Conical (Plate-4, Fig. 3): Shaped like a cone. Eg: *A (H) reticulatus* sp. nov.
4. Obtuse (Plate-4, Fig. 4): Having a blunt apex. Eg: *A (H) crenulus* sp. nov., *V. arboriformes* sp. nov., *A. (H.) keralensis* sp. nov.

5. Rounded (Plate-4, Fig. 5): Assuming a round shape. *A. (H.) reticulatus* sp. nov.

Surfaces of setae exhibit various types of ornamentations as described below:

1. Glabrous (Plate-4, Fig. 6): Entirely devoid of hairs or bristles, smooth-skinned. Eg: *J. minutus* sp. nov., *H. davisi* sp. nov., *M. glabrus* sp. nov., *P. haqi* sp. nov., *A. (H.) keralensis* sp. nov., *A. (H.) reticulatus* sp. nov..
2. Roughened (Plate-4, Fig. 7): Having an uneven or irregular surface, not smooth. Eg: *H. xavieri* sp. nov.
3. Barbed (Plate-4, Fig. 8): Completely covered with fine hairs. Eg: *H. indicus* sp. nov., *V. arboriformes* sp. nov., *V. ramaniae* sp. nov.
4. Ciliate (Plate-4, Fig. 9): With uniformly distributed cilia eg: *P. elongates* sp. nov.
5. Spinose (Plate-4, Fig. 10): Covered with strong, sharply pointed spines, or thorn like structure eg: *H. indicus* sp. nov.
6. Plumosus (Plate-4, Fig. 11): Densely covered all over with long fine hairs. Eg: *V. arboriformes* sp. nov. *V. ramaniae* sp. nov.

Other than setae, notogaster also carries structures like condyles with different shapes, glands, respiratory structures like area porosae, sacculi and pores. Area porosae are regions of notogaster itself, but thinner and are provided with finer pores or tubes. Higher oribatids often possess eight circular area porosae, and Grandjean (1954) called them as Octotaxic organs. They are porosae adalares ($A\alpha$) and area porosae mesonoticae 1-3 (A_1, A_2, A_3). In addition to this, some species

possess a pair of area porosae dorsosejugales (*Ad*), area porosae lateralis (*Al*) along the side of the prodorsum and area porosae post analis (*App*) behind the anal plates. Primitive oribatids may carry extensive, transversely situated irregular or circular area porosae. Some times the area porosae sink below the cuticle into a bag like structure with a slit or dot-like opening on the surface and these structures are called sacculi. They correspond to area porosae in number and position and are designated as *sa*, s_1, s_2 and s_3 . Pori are formed when area porosae almost disappear, leaving a point like pore in their place and are designated as *pa*, p_1, p_2 and p_3. Sometimes they may appear like slits on the notogaster and are called lyrifissures, their maximum number being seven and designated as *ia, ip, ih, ips, iad* and *ian*. Oil glands open through a small aperture, *gla* towards the middle or posterior region of the notogaster.

Micro sculpture of integument (Mahunka and Zomberi, 1985)

An important feature of oribatid mites is the microsculpture of the integument. The pattern of micro sculpture varies from one species to the other and are categorised as follows:

1. Punctulate (Plate-5, Fig. 1): Marked with minute points or dots eg: *P. haqi* sp. nov., *M. glabrus* sp. nov.
2. Punctate (Plate-5, Fig. 2): Marked with points or dots. Eg: *A. (H.) reticulatus* sp. nov., *A. (H.) chaliensis* sp. Nov, *H. indicus* sp. nov.
3. Foveolate (Plate-5, Fig. 3): Marked with small deep pits, interspaces larger than diameter of one pit eg: *A. (H.) keralensis* sp. nov., *A. (H.) crenulus* sp. nov., *A. (H.) chaliensis* sp. nov., *H. davisi* sp. nov.

4. Alveolate (Plate-5, Fig. 4): Marked with large, mostly round spaces, eg: *V. ramaniae* sp. nov.
5. Maculate (Plate-5, Fig. 5): Marked with spots or marks of irregular outline and of different sizes eg:- *P. elongatus* sp. nov.
6. Polygonate (Plate-5, Fig. 6): Marked with fine granules grouped into polygonal masses. Eg: *P. elongatus, A. malabaricus* sp. nov.
7. Granulate (Plate-5, Fig. 7): Covered with small grains eg: *A. plumosus* sp. nov.
8. Rugulose (Plate-5, Fig. 8): Covered with rather fine wrinkles Eg:- *M. glabrus* sp. nov.
9. Rugose (Plate-5, Fig. 9): Covered with wrinkles Eg:- *A. (H.) keralensis* sp. nov.
10. Reticulate (Plate-5, Fig. 10): Forming a fine reticulum eg: *A. (H.) reticulatus* sp. nov.

Some members of the higher oribatids possess wing-like expansions antero-laterally and these are called pteromorphae. They may even extend beyond the body and may curve ventrally over the legs. Pteromorphae may be movable or immovable.

Lateral side

Higher oribatids develop a chitinous, longitudinal ridge called tutorium (*tu*) with a free apex along the lateral side. Special structures called pedotecta form a protective cover for the bases of legs, their usual number being 2, but rarely 3. Pedotectum 1 is longer than the rest. Lateral projections of various shapes called discidia (*dis*) produced from

ventral plate protect the base of IVth leg. In some oribatids a wedge shaped crista called custodium (*cus*) arise from leg IV.

Ventral Region (Plate-1, Fig. 2)

Consists of the gnathosoma, epimere and ano-genital area.

Gnathosoma

The region of the body carrying the oral appendages or mouth parts is called the gnathosoma. It is contained in an anterior cavity called camerostome. The mouth parts consist of the sub or infracapitulum, paired palps (Plate-2, Fig. 9) and chelicerae (Plate-2, Fig. 7). The infracapitulum is the basal part of gnathosoma which consists of an unpaired mentum or hyseterostoma, a dorsal neck or cervix, the paired genae and their continuation in the rutellum (Plate-2, Fig. 5). The articulation between mentum and genae is the labiogenal articulation which can be of the following four types:

1. Anarthric- without any special articulation.
2. Stenarthric- with posteriorly directed labiogenal articulation and mentum appears triangular.
3. Diarthric - with transverse labiogenal articulation and mentum appears quadrangular.
4. Suctorial - with united mento-genal plate.

In suctorial type of labiogenal articulation rutellum becomes modified into tubes. Three pairs of setae are usually seen on the infracapitulum, one pair called *h* on the mentum and two pairs, *a* and *m* on genae. The palps have 2-5 segments and setation is species specific.

Chelicerae may be wide, chewing type or elongated piercing type (peloptoid type). The first type possesses a fixed digit or digitus fixus and a movable digit or digitus mobilis. Both digits bear teeth of varying number and nature. Two setae, *cha* and *chb* are present on the chelicerae.

Epimeral Region (Plate-2, Fig. 6)

The region between infracapitulum and genital plate is known as epimeral or coxisternal region. Laterally it extends upto the coxae of the legs and forms the ventral side of the propodosoma. The four epimeral plates viz., ep_1, ep_2, ep_3 and ep_4 cover this region. The four epimeral plates are bordered by chitinous thickenings called apodemata of which there are five, apo_1, apo_2, apo_3, apo_4 and apo_5 (apodemata sejugalis). The number of setae on the epimera varies in different species and is usually represented by an epimeral setal formula of four figures. The setae are counted on each epimeral plate from the middle towards the margin.

Genito-anal Region (Plate-2, Fig. 8)

The region behind the epimera is occupied by the genital and anal plates. In the primitive types (Macropyline type), the genital and anal plates are in contact with each other and as such extend along the entire length of genito-anal region. But in higher oribatids (Brachypyline type) these two plates do not touch each other and are situated on a distinct ventral plate. A pair of small triangular aggenital plates are seen laterally below the genital plate. A pre-anal plate is located between genital and anal plates. Lateral to the anal plate is a pair of longitudinally placed adanal plates which may be either fused with the

anal plate or may lie separate. Except preanal plate, all others carry setae. In primitive oribatids, the genital plate is divided by a transverse suture and bears 10 pairs of genital setae. Anal plate bears two and adanal plate bears four pairs of setae. In higher oribatids the usual chaetotaxy is six or four pairs of genital setae, one pair of aggenital setae, two pairs of anal setae and three pairs of adanal setae.

Legs

Adult oribatid mites posses four pairs of legs, each formed of five segments: trochanter, femur, genu, tibia and tarsus (proximal to distal). The chaetotaxy varies from species to species and also from leg I (Plate-2, Fig. 10) to IV. This can be indicated in the form of a formula. Tarsus is the longest segment of the leg and it bears the maximum number of setae including the fundamental and accessory setae. Tip of the tarsus bears 1-3 claws depending upon the species. Tarsal segment of leg I is characterised by the presence various setiform organs. Leg setae are of four major types (Norton, 1977).

1. Normal setae (Plate-4, Fig. 12): They are the most abundant setiform organs on legs and are homogeneous with a median cavity and contain actinochitin.
2. Solenidia (Plate-4, Figs. 13-16): They are hollow, thin walled and can be easily distinguished from the others by the lack of actinochitin. They are mainly of four types.
   a. Baculiform: when they have the same diameter throughout.
   b. Ceratiform: when they taper towards the tip.

c. Tactile: when they are very long and flagellate.

d. Piliform: when they are elongated with fine tip.

The solenidial notation varies with segments and accordingly they are noted as sigma (σ) when they are on genu, phi (φ) when they are on tibia and omega (ω) when they are on tarsus.

3. Eupathidia : These are generally seen only on tarsus of leg I and represent modified setae with a hollow canal penetrating the small root and a large alveolus. They are devoid of any ornamentations and are sensory in function. They are the result of regressive evolution.

4. Famuli (Plate-4, Figs. 17-19): Are restricted to tarsal segments. They resemble solenidia but stand out separately by the presence of actinochitin. Their internal surface is not striated but somewhat rugosed. They are also formed by regressive evolution.

PLATE 1

Morphological Characters of a Lohmanniid Mite
Annectacarus plumosus sp. nov.

Fig.. 1 Dorsal view

Fig.. 2 Ventral view

PLATE 1

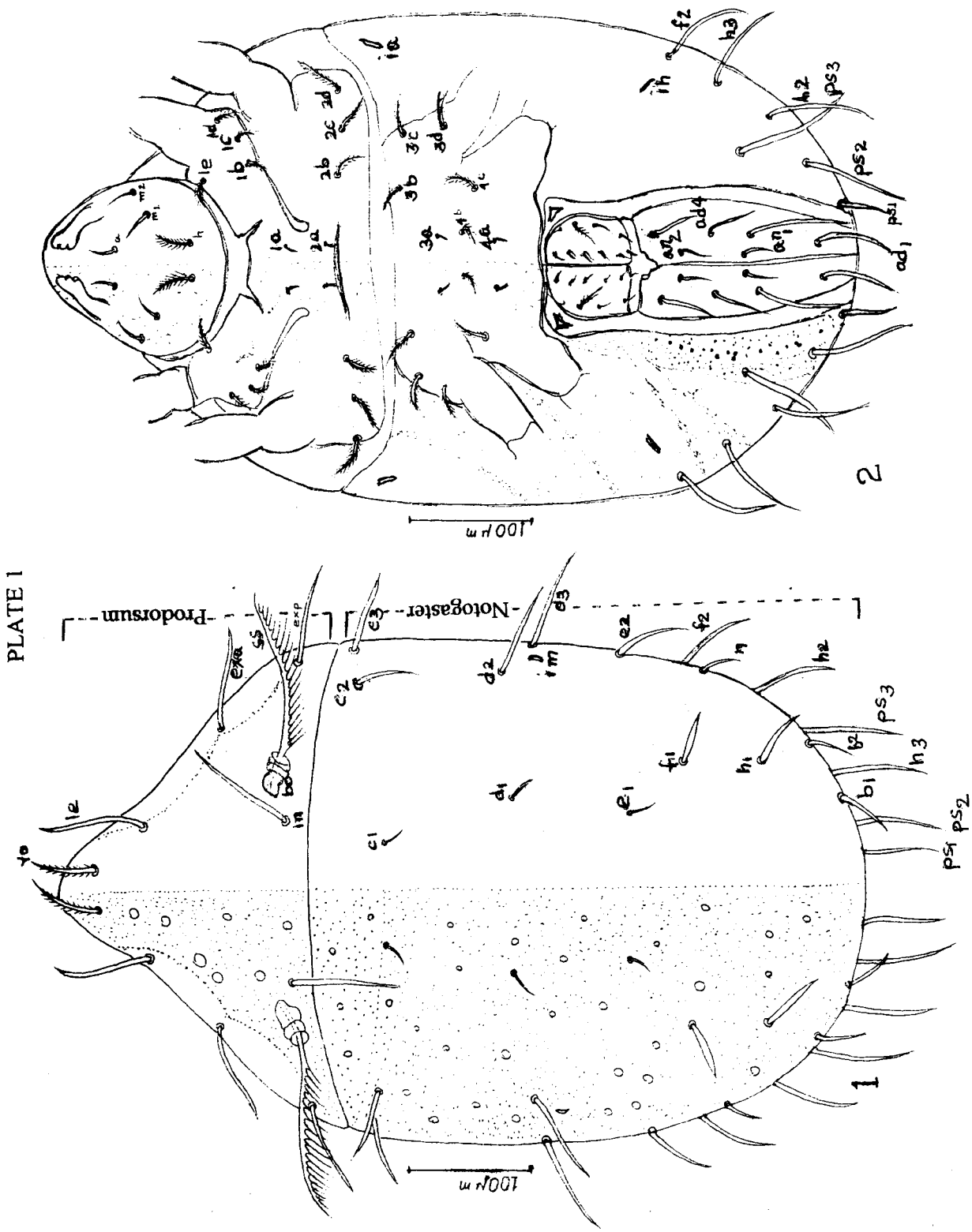

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Plate 2

Morphological Characters of a Phthiracarid Mite
Atropacarus (Hoplophorella) reticulatus sp. Nov

Fig.. 1	Lateral view
Fig.. 2	Dorsal view of the aspis
Fig.. 3	Enlarged view of notogastral seta
Fig.. 4	Bothridium and sensillus
Fig.. 5	Rutellum
Fig.. 6	Epimeral region
Fig.. 7	Chelicera
Fig.. 8	Genital and ano adanal region
Fig.. 9	Pedipalp
Fig.. 10	Leg -1

PLATE 2

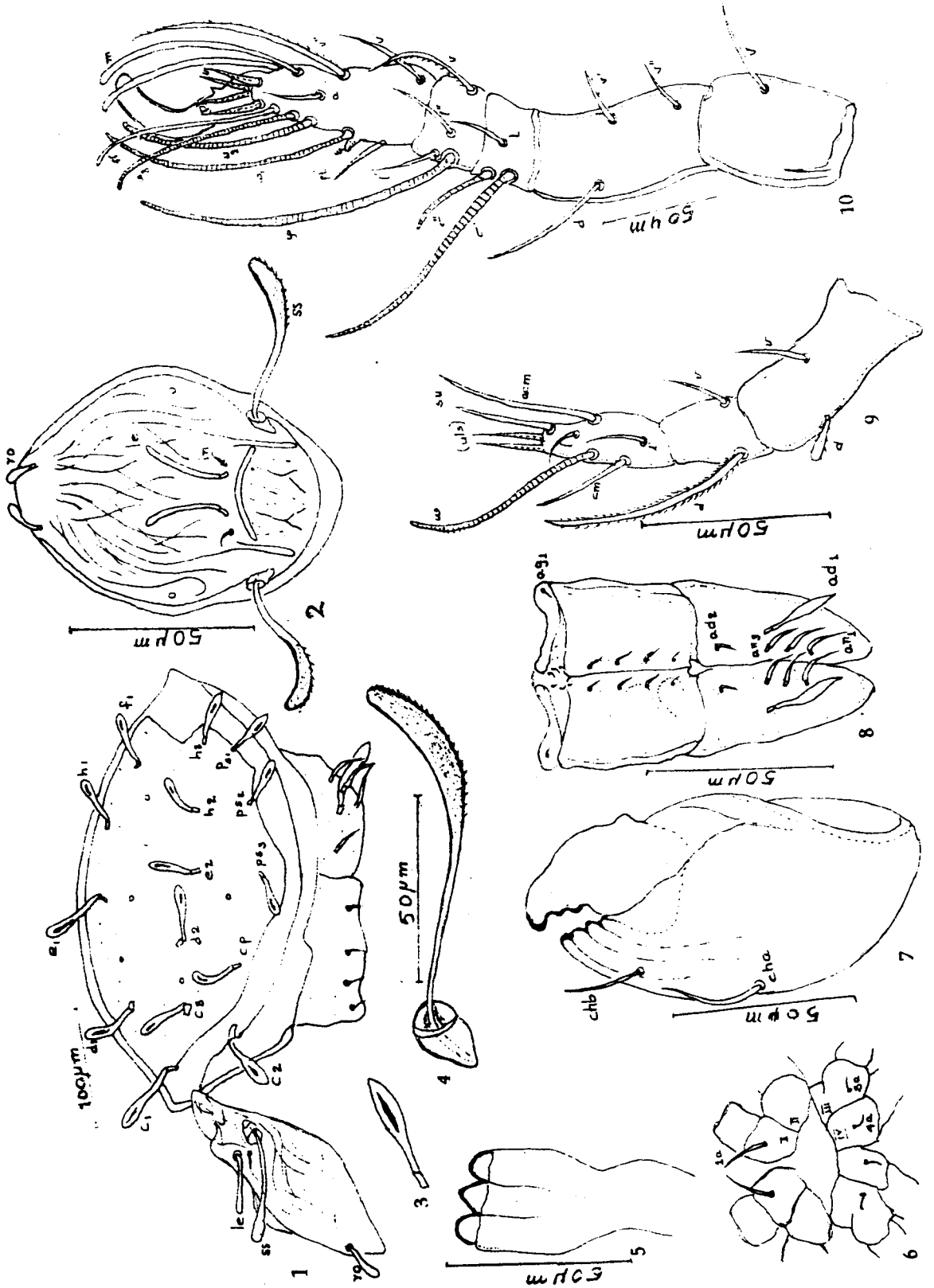

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PLATE 3

Setae in Oribatid Mites

Fig. 1 Flagelliform

Fig. 2 Setiform

Fig. 3 Spiniform

Fig. 4 Clavate

Fig. 5 Foliate

Fig. 6 Arboriform

Fig. 7 Pectinate

Fig. 8 Ciliate

Fig. 9 Pennate

Fig. 10 Brocate

Fig. 11 Entire

Fig. 12 Serrate

Fig. 13 Barbed

Fig. 14 Ciliate

Fig. 15 Spinose

PLATE 3

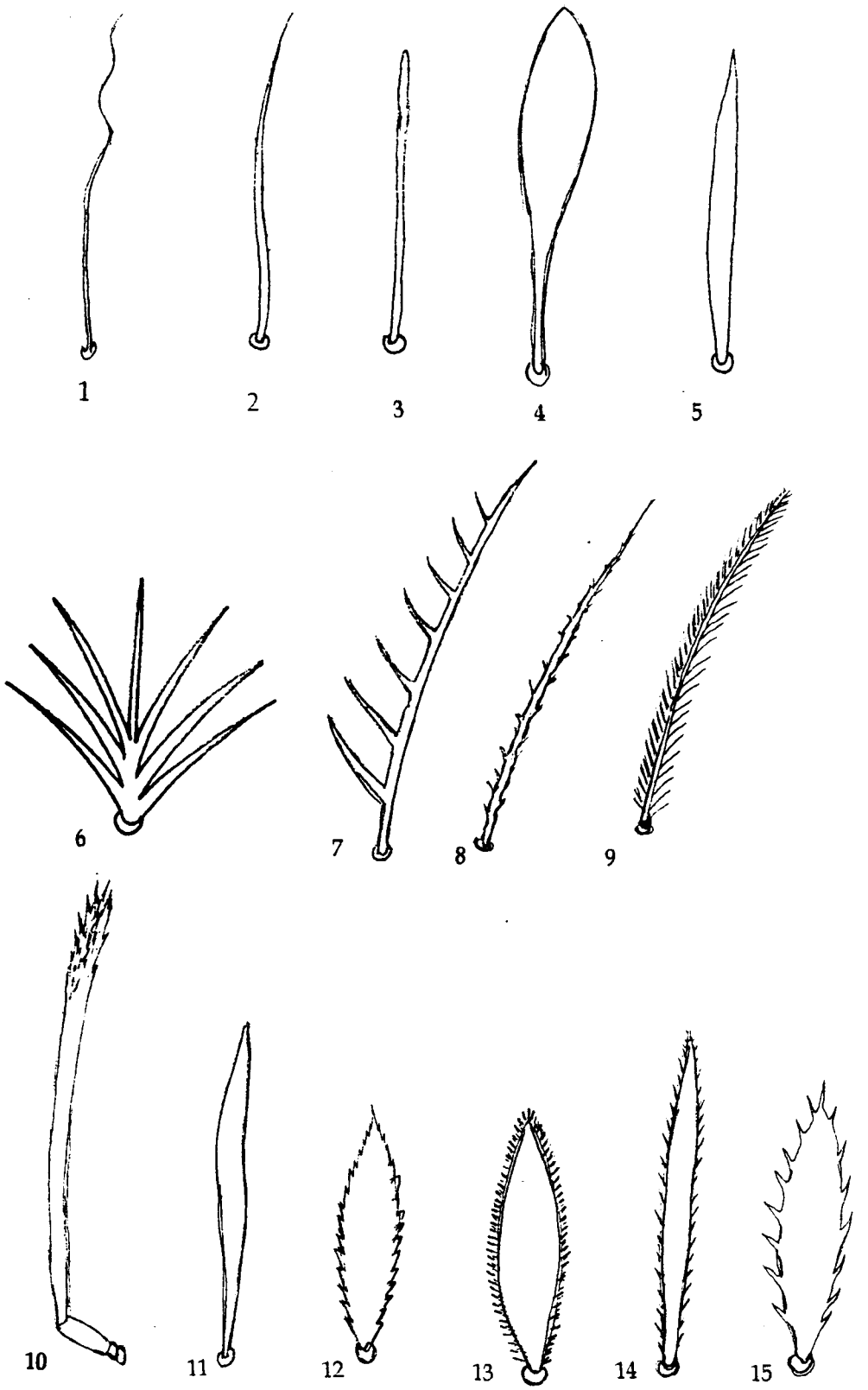

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PLATE 4

Setae in Oribatid Mites

Fig. 1	Acuminate
Fig. 2	Acute
Fig. 3	Conical
Fig. 4	Obtuse
Fig. 5	Rounded
Fig. 6	Glabrous
Fig. 7	Roughened
Fig. 8	Barbed
Fig. 9	Ciliate
Fig. 10	Spinose
Fig. 11	Plumose
Fig. 12	Normal
Fig. 13	Baculiform
Fig. 14	Ceratiform
Fig. 15	Tactile
Fig. 16	Piliform
Fig. 17-19	Famuli

PLATE 4

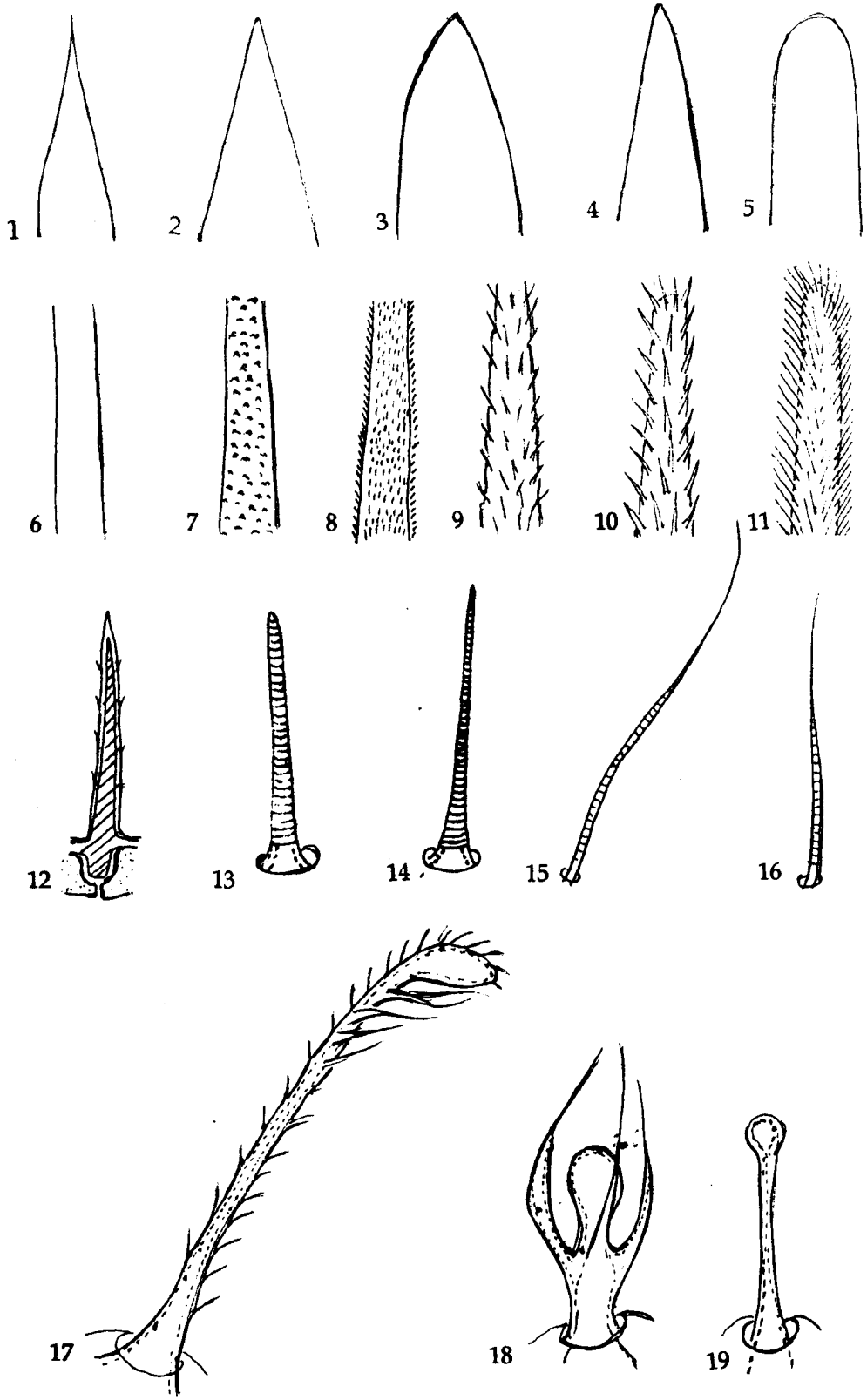

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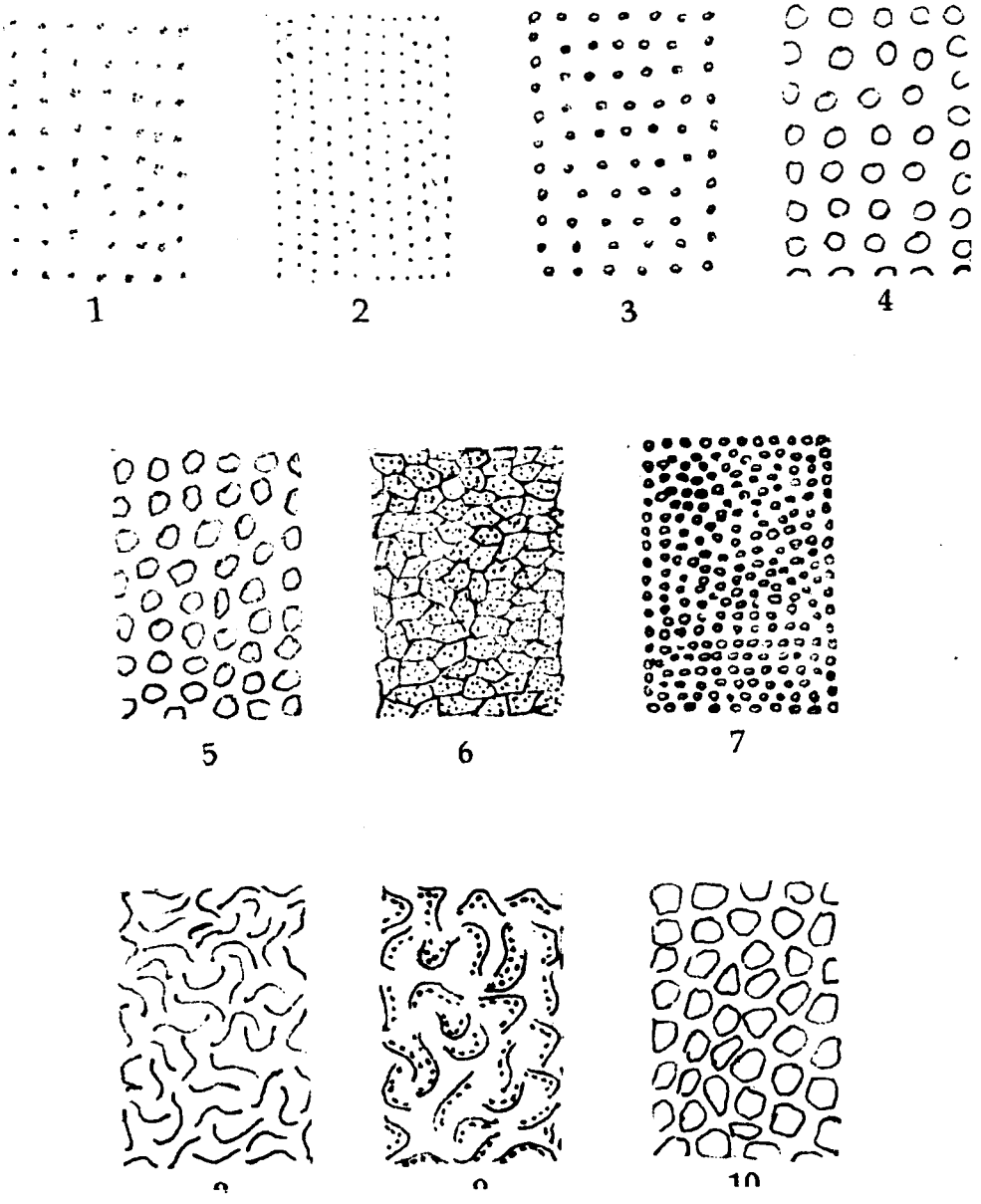
PLATE 5

Microsculpture of Integument

Fig. 1 Punctulate
Fig. 2 Punctate
Fig. 3 Foveolate
Fig. 4 Alveolate
Fig. 5 Maculate
Fig. 6 Polygonate
Fig. 7 Granulate
Fig. 8 Rugulose
Fig. 9 Rugose
Fig. 10 Reticulate

PLATE 5



PART I
MATERIALS AND METHODS

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

MATERIALS AND METHODS

Success of taxonomic and biological studies depends on the availability of sufficient number of organisms concerned. This needs selection and collection of required organisms in large numbers from their natural habitats. Soil is a refuge for soil inhabitants to escape from desiccation and extremes of climate. The characteristic vegetation cover is a good index of the habitability of a given area for soil animals. Generally, conditions which enhance plant growth are equally favourable for the existence of animals also. Oribatid mites are edaphic animals and they abound in areas where there is large accumulations of organic litter in various stages of decomposition. The species composition and population density of oribatid mites in a given habitat depend greatly on the type of vegetation and the extent of organic components present in the soil. Based on this a preliminary sampling involving a few sites from Malappuram and Kozhikode districts was made for the retrieval of mites. Accordingly, two sites each from Malappuram and Kozhikode districts were finally selected viz., Chaliyam beach and Government Arts and Science College Campus, Calicut in Kozhikode district and Calicut University Campus and Kakkancheri in Malappuram district (Plate -6). The sites were vegetationally different in characters from one another (Table 1) and can easily be approached by roads.

1. Area Surveyed

Site I -Calicut University Campus (UC) (Plate-7, Figs. 1-6; Plate-8, Figs. 1-2)

The Calicut University Campus is situated towards the north western part of Malappuram district about 23 KM South of Calicut city, in the latitude of 11^0 35^1-45^1 and longitude of 75^0 45^1 - 50^1 at an altitude of 40-60M above sea level. The campus is vast, extending over an area of 400 hectares. Topography of the campus is unique, the area being profusely laterite with hills and valleys. Soil is a mixture of gravel and red loam which contains a very high percentage of organic debris in low lying areas. This sustain a very rich soil community. The general flora of the Campus consist of about 500 species of angiosperms. Each area of the campus has its own specific groups of native plants and associated fauna. Diversity of the campus can be represented by categorising this site into Botanical Garden (BG), Secondary Forest (SF), Acacia Plantation (AP), Grass Land (GL), Cashew Plantation (CP), Bamboo Groves (BB), Paddy Field (PF) and Agricultural Garden (AG). Though a small percentage of the land has been utilised for constructing buildings of various nature, the rest of the area still remain as maiden land without much human interference. So one can find both natural and artificial ecosystems of varying nature.

The natural ecosystems include forest patches with perennial plants, shrub jungles, grass lands and bamboo groves. The area situated towards the northern side of Pareeksha Bhavan form an isolated patch of forest ecosystem of about 60sq meters. Here the ground is uneven and the soil is of the mull type. The surface of the soil is covered with a thick

layer of fresh and partly decomposed leaves that forms an upper litter layer of 20cm thickness comprising the A 00-layer. This is followed by the fermentation or F-layer of about 5cm thickness where decomposition of leaves is in progress. The H or humus layer below this is of 15cm thickness and composed of plant remains that had been extensively converted into humus. The B layer consists of dark soil with high organic content. The area is characterised by big trees, shrubs, herbs and climbers belonging to several species which prevented direct sunlight reaching the ground.

The University park constitutes a typical grass land ecosystem. The ground has a uniform turf of grass. Periodical cutting of grass gives it a lawny appearance. The peculiarity of this area is that there is practically no litter accumulation on the ground due to the absence of big trees. There is a very thin fermentation layer which can be observed with great difficulty. Underneath this the soil profile is of uniform brownish colour, characterised by superficially scattered roots of the grass.

The area close to the northern boundary of the Campus is characterised by the presence of groups of bamboo groves. Bamboo have grown to a height of about 50-60ft. There is no other vegetation in this area. The fallen leaves and twigs of bamboo have contributed to the formation of a thick layer of litter on the ground. The fermentation layer below the litter layer is of about 5cm thickness and the humus horizon is of about 10cm thickness.

In addition to these specific areas, small patches of shrub jungles can be observed scattered here and there all over the campus. The botanical garden which stretches over an area of 19.5 hectare is a unique feature of the campus. It is one of the best maintained botanical gardens in South India with many rare, exotic and endemic plants. One hundred and ninety three species of flowering plants belonging to 54 families constitute the main flora besides an almost equal number of species of herbs and grass. Towards the South West corner of the garden there is a pond which almost dries up during the peak of summer. Soil is laterite and was characterised by superficially scattered roots. There is some litter accumulation on the ground. But the fermentation layer is very thin. The area around the base of large trees is always covered by a thick layer of litter consisting of fallen leaves and twigs.

A considerable area of the campus is utilised for social forestry programme. Under this programme., *Acacia auriculiformes* has been planted extensively in the campus. The trees have grown to full size providing shade and forming a boundary for the campus. The ground mostly maintain a thick accumulation of leaves and twigs. The Campus is also noted for its cashewnut plantations. Open spaces between the buildings are occupied by a large number of cashewnut trees where the ground has a thick accumulation of cashew leaf litter. The western part of the campus is formed of low lying areas which has been converted into paddy fields. Facilities for artificial irrigation allow two crops of paddy annually. Here soil is almost water logged during crop season and hard and dry during the period in between. Close to these paddy

fields are vegetable gardens where various types of vegetables belonging to leguminous plants, fruit vegetables, green and leafy vegetables, cucurbitaceous crops, tuber crops, corms and rhizomes are cultivated extensively.

Site II – Kakkanchery Site (KS) (Plate-8, Fig. 3)

The second study site is situated about 8km towards the north of Calicut University. The site is located close to the National Highway lying about 40ft below the level of the NH. The total area of the site is about eight acres but collection was restricted to areas mainly surrounding trees belonging to the species *Xylea zylocarpa*. The area is overgrown by shrubs, herbs and a variety of trees. The surface of the soil is covered with a thick layer of fresh and partly decomposed leaves forming about 20cm thickness. Below this is the fermentation layer of about 5cm thickness, where decomposition is in progress. The humus layer is 15cm in thickness. Soil is of mull type, almost black in colour and rich in organic content.

Site III – Chaliyam Beach (CB) (Plate-8, Fig. 4)

The third study site viz., the Chaliyam beach is situated about 28km away from Calicut city. During the South West monsoon, the site is almost inundated with water due to high tides. Wood debris carried down by the waves during successive years have accumulated all along the beach. Sufficient accumulation of wood debris in various decomposition stages provide ample scope for the replenishment of a good ground flora intervened by patches of shell accumulation. Plant

materials in various stages of decomposition and molluscan shells formed two large mounds, providing excellent habitats for many species of littoral animals and soil arthropods. An interesting feature of the beach is the scattered growth of *Calotropis gigantea* and the grass *Spinefex littoreus* slightly above the tide mark. The ground has accumulation of decaying wood, leaves and roots of these plants mixed with the drift wood brought by the tides and waves. The beach is sandy in nature formed by loose sand.

Site IV –Government Arts And Science College Campus (GC) (Plate-8,Fig. 5)

The campus of Government Arts and Science College, Calicut formed the fourth study site. It is situated about 20km north of Calicut University campus. The campus has an area of about four acres. The central part of the campus is occupied by the college building while the boundaries support a good vegetation. The ground is even and the soil is of the mull type. Along the boundary of the campus the ground is covered by fresh and partly decomposed leaves which form a litter layer of about 10 cm thickness. Below this there is a fermentation layer of 5cm thickness characterised by decomposing leaves. Hence soil is brownish black in colour. This layer is followed by a humus horizon of about 15 cm thickness where soil is much darker than the layer above. This layer is well aerated and support a variety of soil animals.

As the four study sites are located within a radius of 30 KM, there is not much variation in their climatic factors. The climate is typical of temperate areas with roughly four distinguishable seasons

round the year. Towards the end of January, the summer season starts which goes till the end of May. During the peak of summer, the day time temperature may reach a maximum of 36 to 37^{0}C. With the onset of rainy season in June all sites experience profound rainfall by South-West and North-East monsoon performing an average of 300cm/year. Towards the middle of August the climate become more pleasant, marking the advent of spring with occasional rains especially during October. By November, the areas start to experience the winter cold which may extend up to the end of January. The moisture content of the atmosphere is high throughout the year. The relative humidity fluctuate between 60-95%. The minimum recorded temperature during the period of study is 19^{0}C while maximum is 37^{0}C.

2. Collection of Soil Samples

Mites were collected from the above sites for a period of three years. During the study period soil samples were collected early in the morning hours between 7-8. Samples were collected at random within the study areas. During sampling, soil along with partially decomposed litter were carefully removed from the upper 5cms using a shovel. A rectangular iron corer measuring 10cm height and 5cm diameter was used for the purpose. The collected samples were transferred into plastic bags with appropriate labels and transported to the laboratory as early as possible for the purpose of extraction. Samples of partly decomposed plant parts, algae, fungi, lichen and moss were also collected for separation of mites as well as for using them as test food in the

laboratory. Maximum care was taken while handling the samples during collection and subsequent transportation.

3. Extraction of Mites

The soil and litter samples collected from the various study areas were subjected to extraction for collection of oribatid mites. The process of extraction was carried out using a series of modified Berlese- Tullgren funnel apparatus.

3a. Principle of Extraction

The extraction technique was based on Berlese's (1905) original funnel apparatus modified by Tullgren (1918).

Soil animals including oribatid mites were highly sensitive to the intensity of light and heat in the environment and desiccation of soil in which they live. Majority of soil animals were negatively phototropic and hence when exposed to heat and light, they try to move away. This behaviour of soil animals was best utilised for their extraction from soil here. Desiccation of the soil sample by heat helped to drive the fauna from top to bottom and gradually out of the sample, through the sides of the funnel into the collecting vial. Larger animals during this process could escape through the gap between the lower rim and base of the sample container.

3b. Extraction Apparatus (Plate-9 Figs. 1 & 2)

The extraction unit was designed specifically for the separation of soil organisms. It was assembled locally on four legs within a

rectangular steel frame measuring 168 cm x 90 cm. Two rows of wooden planks, each with 12 holes for holding the funnels and sample container were fitted into the steel frame. Each row carried extraction units arranged in two parallel series of six sets thus accommodating a total of 24 units. This arrangement enabled simultaneous extraction of large quantities of soil samples. Each extraction unit was complete in itself with an electric bulb acting as a heat and light source, a vessel for holding the soil sample and a suitable vial for collecting the extracted animals. The electric bulbs were fitted in such a way so as to face the sample containers kept immediately below. The average distance between the bulb and sample was kept at 12cm, but this could be adjusted as required by raising or lowering the wooden planks with the help of screws provided at the corner. Depending on the moisture content of the soil and thickness of sample, a bulb with required voltage was selected. During summer, when samples were rather dry, 25 or 40w bulbs were used, while during rainy season 100w bulb was used.

The soil sample for extraction was taken in a brass cylinder with a diameter of 15 cm and height of 10cm. The cylinder rested on a circular fine wire mesh of 0.8 mm mesh size and 15 cm diameter. This served as the bottom of the container. There was a gap of 1 cm between the wire mesh and the lower rim of the cylinder. A round resting shield with a diameter of 19cm with larger mesh size of 0.5 cm was kept below the sample container. The resting shield was provided with two vertical rods on opposite sides bearing hooks at the tip. With the help of these rods the sample container along with the resting shield could be

removed or replaced without causing any disturbance to the sample inside. The resting shield rested on the rim of a brass funnel. The funnel had a height of 20cm with a wide mouth at the upper surface where it measured 16cm in diameter where as the lower tail end had a height of 5cm and diameter of 2cm. The funnel was conical in shape with steep and smooth inner surface. The upper rim of the funnel was flattened forming a platform having 20 cm in diameter with raised edges so that it could tightly fit into the hole in the wooden plank, providing space for accommodating sample container also.

Animals emerging from the samples and falling along the sides of the funnel were gathered in a collecting vial kept beneath each funnel. A plastic or glass specimen tube of 6cm. length and 2cm diameter formed the collecting vial. The vial rested on a spring welded to a circular metallic concave support. The spring mechanism helped to fix the vial in position.

3c. Extraction of Mites for Taxonomic Studies

Soil samples for extraction were placed in the sample containers in an inverted position. The distance between sample and light/heat source was adjusted as per requirements and the bulbs were switched on. The combined effect of heat and light caused gradual desiccation of the soil sample, there by compelling the cryptic mites to come out of the soil. On reaching the fine mesh screen they fell into the collecting vials. Depending on the moisture content of the soil sample, the period of extraction varied from 48 to 72 hours. About 5ml of 70% alcohol was taken in the collecting vial and kept under the funnel. This helped to

preserve the animals falling into the vial. Mites collected in this way were used for taxonomic studies. Plate-9, Fig. 3 provides a view of the mites extracted.

3d. Preparation of Mites

The preserved mites in the vials were transferred into petridishes and sorted out using a fine needle and camel hair brush No. 1 under a stereomicroscope of 30x magnification. They were dehydrated by upgrading in alcohol series and were finally transferred to vials containing clearing medium. The clearing medium was prepared by mixng absolute alcohol and lactic acid in the ratio 1:1. The vials were closed with cotton plugs and kept at room temperature in plastic containers. The time allowed for clearing depended on the sclerotisation of the mite species. Well cleared specimens were mounted on microscopic slides for examination.

3e. Mounting of Cleared Specimens

Two types of mounting of mite specimens were practiced during the current study.

a) Temporary mounting: This was followed for routine and immediate observation of cleared specimens. For this, a drop of glycerine was placed in the centre of a clean microscopic slide. The mite was then transferred carefully into glycerine. After orienting the specimen properly, a glass bristle larger than the size of the mite was placed near the specimen. This helped to manipulate and maintain the mite in the desired position. The use of glass bristle larger than the size of the mite

enabled to prevent crushing of the mites while mounting. The specimen was then mounted using a cover glass of 18mm diameter.

b) Permanent mounting: Permanent slides were prepared either in Polyvinyl alcohol or Hoyer's medium (Baker and Wharton, 1952). This was done by transferring a drop of the medium in the centre of the microscopic slide. The specimen was placed in position using a fine camel hair brush. It was then oriented in the desired position using glass bristles as mentioned above and was covered by the cover glass. The prepared slides were kept at 50°C in an incubator until desired clarity was obtained. After this, the cover glass was sealed with commercial nail polish. Slides were properly labelled and stored in slide boxes.

Mounting media

a. Polyvinyl Medium

1. Elvanol 71-24 (Du Pont Polyvinyl Alcohol) dissolved in 4 volumes of distilled water at 90°C.
2. Filtered the solution
3. Concentrated the clear filtrate in a water bath until solution became syrupy.
4. Added 22 parts of lactic acid to 56 parts of PVA and used for mounting.

b. Hoyer's medium

1. Weighed 30 gm of gum arabic and 200 gm of chloral hydrate and transferred the same into a 1000 ml beaker.
2. Added 50 ml of distilled water.

3. Added 20 ml of glycerine and thoroughly mixed at room temperature.
4. Filtered this mixture and used for mounting.

3f. Identification of Mites

Identification of known mite species was done by comparing its morphological characters with those given in literature and figures of species concerned. Morphological characters were studied under a Leitz Aristoplan Research Microscope and sketches were drawn using Wild Leitz GMBH Camera Lucida. Identification of mites was carried out following Balogh (1965, 1972) Balogh and Mahunka (1980) and Haq and Ramani (2003). Erection of new species was made after critical analysis of the novel characters detected and consulting with the guide and other experts in the field. Measurements of the specimens were taken using calibrated ocular micrometer employing stage micrometry. The method suggested by Aoki (1965a) was followed for entering measurements of the body or body parts.

4. Influence of Environmental Factors on Oribatid Mites

Population density of oribatid mites is greatly influenced by various physico-chemical and biological factors of the habitat in which they live. Of the various physical factors, rainfall and temperature exert a profound influence on the population build up of oribatid mites. Similarly the quantity and quality of litter act as a biological barrier in the distribution of oribatid mites. Hence, in the present study, an attempt was made to assess the influence of the above environmental

factors on the population density of oribatid mites. For this regular monthly collection of oribatid mites from the four different study sites characterised by varying degrees of litter accumulation was carried out for a period of one year from September, 2001 to August, 2002. The total number of oribatid mites collected during each month from the four sites was calculated by actual counting and the results were tabulated. Data regarding monthly rainfall and temperature were obtained from Manual Observation Station unit of Centre for Water Resource Development and Management (CWRDM), Kunnamangalam, Calicut. Extent of litter accumulation in each site was also noted. The tabulated data was then represented graphically. Correlation coefficient of population density with respect to rainfall and temperature was analysed statistically using Karl Pearson's measure.

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2\Sigma(y-\bar{y})^2}}$$

where x and y are variables for which the correlation is to be found out and $\bar{x}$ and $\bar{y}$ are the mean value of x and y (Bishop, 1966)

Table 1 - Floral Composition of the Four Study Sites

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
1.	Acanthaceae	1.	*Adhathoda zeylanica* Linn.	+	-	-	-	-	-	-	-	-	-	-
		2.	*Agave vasica* Linn.	+	-	-	-	-	-	-	-	-	-	-
		3.	*Thunbergia grandiflora* Roxb.	+	-	-	-	-	-	-	-	-	-	-
		4.	*T. erecta* Roxb.	+	-	-	-	-	-	-	-	-	-	-
2.	Agavaceae	5.	*Agave anguslifolia* Linn.	+	-	-	-	-	-	-	-	-	-	-
		6.	*A. sisalana* Linn.	+	-	-	-	-	-	-	-	-	-	-
		7.	*Cordyline terminalis* Linn.	+	-	-	-	-	-	-	-	-	-	-
		8.	*Furcraea foetida* Linn.	+	-	-	-	-	-	-	-	-	-	-
		9.	*F. gigantea* Linn.	+	-	-	-	-	-	-	-	-	-	-
		10.	*Pleomale angustifolia* Roxb.	+	-	-	-	-	-	-	-	-	-	-
		11.	*Sansevieria fruticosa* Bi.	+	-	-	-	-	-	-	-	-	-	-
3	Anacardiaceae	12.	*Anacardium occidentale* Linn.	+	-	-	-	+++	-	-	-	-	-	-
		13.	*Holigarna arnottiana* Linn.	+	-	-	-	-	-	-	-	-	-	-
		14.	*Mangifera indica* Linn.	++	++	-	-	-	-	-	-	+	-	+
		15.	*Semecarpus anacardium* Linn.	+	-	-	-	-	-	-	-	-	-	-
4	Amaranthaceae	16.	*Amaranthus tricolor* Linn.	-	-	-	-	-	-	-	++	-	-	-
5	Anonaceae	17.	*Anona squamosa* Linn.	+	-	-	-	-	-	-	-	+	-	+
		18.	*A muricata* Linn.	+	-	-	-	-	-	-	-	-	-	-
		19.	*Artabotrys odoratissimus* (Roxb.) R. Br.	+	-	-	-	-	-	-	-	-	-	-
		20.	*Cnanaga odorata* (Lena) Hook F. Thorms.	+	-	-	-	-	-	-	-	-	-	-
		21.	*Polyalthia longfolia* (Sommerat) Theo.	++	+	-	-	-	-	-	-	-	-	+
		22.	*P. korinti* (Dunal) Bentho & Hook	+	-	-	-	-	-	-	-	-	-	-

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
6	Apocyanaceae	23.	*Allamanda cathartica* Linn.	+	-	-	-	-	-	-	-	-	-	-
		24.	*A neriifolia* Linn.	+	-	-	-	-	-	-	-	-	-	-
		25.	*A violacea* Linn.	+	-	-	-	-	-	-	-	-	-	-
		26.	*Echites scholaris* Linn.	+	-	-	-	-	-	-	-	-	-	-
		27.	*Holarrhena pubescens* Linn.	+	-	-	-	-	-	-	-	-	-	-
		28.	*Cerebra fruticosa* Linn.	+	-	-	-	-	-	-	-	-	-	-
		29.	*Nerium oliander* Linn.	+	-	-	-	-	-	-	-	-	-	-
		30.	*N. indicum* Linn.	+	-	-	-	-	-	-	-	-	-	-
		31.	*N. odorum* Linn.	+	-	-	-	-	-	-	-	-	-	-
		32.	*Plumeria rubra* Linn.	+	-	-	-	-	-	-	-	-	-	-
		33.	*Roupellia grata* (Francho) Wall. & Hook.	+	-	-	-	-	-	-	-	-	-	-
		34.	*Strophanthus wightianus* Linn.	+	--	-	-	-	-	-	-	-	-	-
		35.	*Thevetia peruviana* (Pers.) Merr.	+	-	-	-	-	-	-	-	-	-	-
		36.	*Tabernnemontiana heyneana* Wall.	-	++	-	-	-	-	-	-	-	-	-
		37.	*Wrightia arborea* (Dennst) Mebb.	+	-	-	-	-	-	-	-	-	-	-
7	Arecaceae	38.	*Areca catechu* Linn.	+	-	-	-	-	-	-	-	-	-	-
		39.	*Arecastrum romanzoffianum* Beu.	+	-	-	-	-	-	-	-	-	-	-
		40.	*Caryota urens* Linn.	+	-	-	-	-	-	-	-	-	-	-
		41.	*Chrysalidocarpus lutescans* H. Windl.	+	-	-	-	-	-	-	-	-	-	-
		42.	*Cocos nucifera* Linn.	+	-	-	-	-	-	-	-	-	-	-
		43.	*Elaeis guvanensis* Jacq.	++	-	-	-	-	-	-	-	+	-	+
		44.	*Licutila peltata* Linn.	+	-	-	-	-	--	-	-	-	-	-
		45.	*Roystonea regia* (HBK) O. F. Cook	+	-	-	-	-	-	-	-	-	-	-
		46.	*Cryptostegia grandiflora* Linn.	+	-	-	-	-	-	-	-	-	-	-

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
8.	Araceae	47.	*Amorphophalus paecomifolius* Linn.	-	-	-	-	-	-	-	++	-	-	-
		48.	*Colocasia esculenta* Schott.	-	-	-	-	-	-	-	+++	-	-	-
9.	Asciepiadaceae	49.	*Calotropis gigantea* R. Br.	-	-	-	-	-	-	-	-	-	+++	-
10.	Asteraceae	50.	*Vernonia eleganifolia* D. C.	+	-	-	-	-	-	-	-	-	-	-
11.	Averrhoaceae	51.	*Averrhoa crambola* Linn.	+	-	-	-	-	-	-	-	-	-	-
12.	Bigoniaceae	52.	*Kigelia africana* (Lamk) Benth.	+	-	-	-	-	-	-	-	-	-	-
		53.	*Mellingtonia hortensis* Linn.	+	-	-	-	-	-	-	-	-	-	-
		54.	*Saritaea magnifica* (steen) Dugand	+	-	-	-	-	-	-	-	-	-	-
		55.	*Spathodea companulata* Linn.	+	-	-	-	-	-	-	-	-	-	-
		56.	*Tabibua argentea* Brett.	+	-	-	-	-	-	-	-	-	-	-
		57.	*Tecoma stans* (Linn) Kunth.	+	-	-	-	-	-	-	-	-	-	-
13	Bixa ceae	58.	*Bixa orellana* Linn.	+	-	-	-	-	-	-	-	-	-	-
14	Bombacaceae	59.	*Ceiba pentandra* (Linn.) Gaertm.	+	-	-	-	-	-	-	-	-	-	-
		60.	*Ochroma grandiflorum* Linn.	+	-	-	-	-	-	-	-	-	-	-
15	Caesalpiniaceae	61.	*Bauhimia purpura* Linn.	+	-	-	-	-	-	-	-	-	-	-
		62.	*B. tomentosa* Linn.	+	-	-	-	-	-	-	-	-	-	-
		63.	*Brownea ariza* Benth.	+	-	-	-	-	-	-	-	-	-	-
		64.	*Caesalpinia coriaria* (Jacq.) Willd.	++	-	-	-	-	-	-	-	+	-	+
		65.	*Cassia biflora* Linn.	+	-	-	-	-	-	-	-	-	-	-
		66.	*C. fistula* Linn.	+	-	-	-	-	-	-	-	-	-	-
		67.	*C. javancia* Linn.	+	-	-	-	-	-	-	-	-	-	-
		68.	*C. nodosa* Linn.	+	-	-	-	-	-	-	-	-	-	-
		69.	*Delonix regia* (Boj ex Hook) Raf.	+	-	-	-	-	-	-	-	-	-	-
		70.	*Haematoxylum compechianum* Linn.	+	-	-	-	-	-	-	-	-	-	-
		71.	*Peltophorum pterocarpum* (DC) Buker ex Heyne	+	-	-	-	-	-	-	-	+	-	-
		72.	*Saraca asoka* (Roxb.) Willd.	+	-	-	-	-	-	-	-	-	-	-
		73.	*Tamarindus indica* Linn.	+	-	-	-	-	-	-	-	+	-	+

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
16	Casuarinaceae	74.	*Casuarina equisetifolia* Linn.	++	+	-	-	-	-	-	-	+	-	+
17	Celestraceae	75.	*Lophopetalum wightianum* Arn.	+	-	-	-	-	-	-	-	+	-	-
18	Clusiaceae	76.	*Calophyllum apetalum* Willd.	+	-	-	-	-	-	-	-	-	-	-
		77.	*Clusia rosea* Linn.	+	-	-	-	-	-	-	-	-	-	-
		78.	*Garcinia livingstonei* Linn.	+	-	-	-	-	-	-	-	-	-	-
		79.	*G. pictorius* Linn.	+	-	-	-	-	-	-	-	-	-	-
		80.	*Mesua ferrea* Linn.	+	-	-	-	-	-	-	-	-	-	-
19	Convolvulaceae	81.	*Ipomaea batatas* Linn.	-	-	-	-	-	-	-	+	-	-	-
20	Compositae	82.	*Chromolaena odorata* Linn.	-	+	-	-	-	-	-	-	+	-	+
21	Cucurbitaceae	83.	*Citrullus vulgaris* Schrad.	-	-	-	-	-	-	-	+	-	-	-
22	Cacinaceae	84.	*Mappia foetida* Linn.	-	+	-	-	-	-	-	-	-	-	-
23	Combretaceae	85.	*Calicopteris floribunda* (Roxb.) Poivet.	+	++	-	-	-	-	-	-	+	-	-
		86.	*Quisqualis indica* Linn.	+	-	-	-	-	-	-	-	-	-	-
		87.	*Terminalia arjuna* (Roxb.) Poivet.	+	-	-	-	-	-	-	-	-	-	-
		88.	*T. catappa* Linn.	+	-	-	-	-	-	-	-	-	-	++
24	Dilleniaceae	89.	*Dillenia indica* Linn.	+	-	-	-	-	-	-	-	-	-	-
25	Dipterocarpaceae	90.	*Hopea ponga* (Dennst.) Mabherty	+	-	-	-	-	-	-	-	-	-	-
		91.	*Vateria indica* Linn.	+	-	-	-	-	-	-	-	-	-	-
26	Ebenaceae	92.	*Diospyros buxofolia* (Blume.) Hiern.	+	-	-	-	-	-	-	-	-	-	-
27	Elaeocarpaceae	93.	*Mantingia calabitra* Linn.	+	-	-	-	-	-	-	-	-	-	-
28	Euphorbiaceae	94.	*Acalypha hispida* Burm.	+	-	-	-	-	-	-	-	-	-	-
		95.	*Antidesma ghaesembilla* Gaertn.	+	-	-	-	-	-	-	-	-	-	-
		96.	*Bridelia retusa* (Linn.) Spr.	+	-	-	-	-	-	-	-	-	-	-
		97.	*Breynia rhamnoides* Linn.	-	++	-	-	-	-	-	-	-	-	-
		98.	*Codiaeum variegatum* (Linn.) Blume.	+	-	-	-	-	-	-	-	-	-	-

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
		99.	*Croton variegatus* Linn.	++	-	-	-	-	-	-	-	-	-	-
		100.	*Euphorbia pulcherrima* Willd.	+	-	-	-	-	-	-	-	-	-	-
		101.	*Excoecaria cochinchinesis* Lour.	+	-	-	-	-	-	-	-	-	-	-
		102.	*Suregada multiflora* Linn.	+	-	-	-	-	-	-	-	-	-	-
		103.	*Glochidion zeylanicum* (Gaextn.) A. Juss.	+	-	-	-	-	-	-	-	-	-	-
		104.	*Hevea braziliensis* Linn.	+	-	-	-	-	-	-	-	-	-	-
		105.	*Jatropha multifida* Linn.	+	-	-	-	-	-	-	-	-	-	-
		106.	*Manihot glaziovii* Mull. Arg.	+	-	-	-	-	-	-	-	-	-	-
		107.	*Phyllanthus emblica* Linn.	+	-	-	-	-	-	-	-	-	-	-
		108.	*P. myrtifolius* Linn.	+	-	-	-	-	-	-	-	-	-	-
		109.	*Sapium insigne* (Royle.) Benth.	+	++	-	-	-	-	-	-	-	-	-
		110.	*Flacourtia ramantichi* Linn.	+	-	-	-	-	-	-	-	-	-	-
		111.	*Hydrocarpus pentandra* Buch-ham	+	-	-	-	-	-	-	-	-	-	-
29	Gentiaceae	112.	*Oncoba spinosa* Linn.	+	-	-	-	-	-	-	-	-	-	-
30	Goodeniaceae	113.	*Scaevola sericea* Forst.	+	-	-	-	-	-	-	-	-	-	-
31	Lauraceae	114.	*Cinnamonum camphora* Linn.	+	-	-	-	-	-	-	-	-	-	-
32	Lecythidaceae	115.	*Barringtonia acutangula* (Linn.) J. S. Prest.	+	-	-	-	-	-	-	-	-	-	-
33	Licaceae	116.	*Leea indica* Linn.	-	++	-	-	-	-	-	-	-	-	-
34	Loganiaceae	117.	*Fagracea ceilanica* Tumb.	+	-	-	-	-	-	-	-	-	-	-
35	Fabaceae	118.	*Samanea saman* Linn.	+	-	-	-	-	-	-	-	-	-	++
		119.	*Xylea zylocarpa* Linn.	+	-	-	-	-	-	-	-	+++	-	-
		120.	*Desmodium triflorum* Linn.	-	+	-	-	-	-	-	-	++	-	-
36	Lythraceae	121.	*Largerstroemia hirsute* (Lamk.) Willd.	+	-	-	-	-	-	-	-	-	-	-
		122.	*Michelin champaca* Linn.	++	-	-	-	-	-	-	-	+	-	-

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
37	Malvaceae	123.	*Hibiscus rosa-sinensis* Linn.	++	-	-	-	-	-	-	--	-	-	++
		124.	*H. tiliaceus* Linn.	+	-	-	-	-	-	-	-	-	-	-
		125.	*Abelmoschus esculentus* Linn.	-	+	-	-	-	-	-	-	+	-	-
38	Melastonata ceae	126.	*Osbeckia truncata* Linn.	+	-	-	-	-	-	-	-	+++	-	-
39	Meliaceae	127.	*Azadirachta indica* Juss.	+	-	-	-	-	-	-	-	-	-	-
		128.	*Swietenia mahagoni* (Linn.) Jacq.	+	-	-	-	-	-	-	-	-	-	-
40	Mimosaceae	129.	*Acacia auriculiformes* Linn.	+	-	+++	-	-	-	-	-	-	-	+
		130.	*Adenanthera pavonina* Linn.	+	-	-	-	-	-	-	-	-	-	-
		131.	*Pithecolobium pudica* Benth.	+	-	-	-	-	-	-	-	-	-	+
		132.	*Mimosa pudica* Linn. Lamk.	+	+	-	-	-	-	-	-	+++	-	++
41	Moraceae	133.	*Artocarpus heterophyllus* Lamk.	++	-	-	-	-	-	-	-	+	-	++
		134.	*Ficus auriculata* Lour.	+	-	-	-	-	-	-	-	-	-	++
		135.	*F. benjamina* Linn.	+	-	-	-	-	-	-	-	-	-	-
		136.	*F. krishnae* C. Dc	++	-	-	-	-	-	-	-	-	-	-
		137.	*Morus australis* Poiriet	+	-	-	-	-	-	-	-	-	-	-
42	Moringaceae	138.	*Moringa oleifora* Lan.	+	-	-	-	-	-	-	-	-	-	-
43	Musaceae	139.	*Ensete superbam* (Roxb.) Cheesman	+	-	-	-	-	-	-	-	-	-	-
		140.	*Musa paradisiaca* Linn.	+	-	-	-	-	-	-	+	+	-	-
44	Myristicaceae	141.	*Myristica fragrans* Houtt.	+	-	-	-	-	-	-	-	-	-	-
		142.	*Embelia tsjerian* Cotton. A.DC.	+	-	-	-	-	-	-	-	-	-	-
45	Myrtaceae	143.	*Callistemon citrinus* (Cant.) Skaeels	+	-	-	-	-	-	-	-	-	-	-
		144.	*Eucalyptus tereticornis* Linn.	++	-	-	-	-	-	-	-	-	-	-
		145.	*Psidium guajava* Linn.	+	-	-	-	-	-	-	-	-	-	-
		146.	*Syzygium caryophyllatum* (Linn.) Alston.	+	-	-	-	-	-	-	-	-	-	-
46	Nyctaginaceae	147.	*Bougainvillaea spectabilis* Willd.	++	-	-	-	-	-	-	-	-	-	++

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
47	Oleaceae	148.	*Ligustrum gumblei* Raman	+	-	-	-	-	-	-	-	-	-	-
48	Papilionaceae	149.	*Dalbergia sissoo* Roxb.	+										
		150.	*Pisum sativum* Linn.	-	-	-	-	-	-	-	++	-	-	-
		151.	*Dolichos lablab* Linn.	-	-	-	-	-	-	-	++	-	-	-
		152.	*Pongamia pinnata* (Linn.) Pierre.	+	-	-	-	-	-	-	-	-	-	-
49	Rubiaceae	153.	*Benkara malabarica* (Lamk.) Trivengadum.	+	-	-	-	-	-	-	-	-	-	-
		154.	*Canthium anguisti folium* Roxb.	+	-	-	-	-	-	-	-	-	-	-
		155.	*Ixora coccinea* Linn.	+	-	-	-	-	-	-	-	+	-	-
		156.	*Mitragyna parvifolia* Linn.	-	+	-	-	-	-	-	-	+	-	-
		157.	*Mussaenda belilla* Ham.	++	-	-	-	-	-	-	-	-	-	-
		158.	*Ophiorrhiza prostrata* Linn.	+	++	-	-	-	-	-	-	++	-	-
50	Rutaceae	159.	*Citrus acida* Roxb.	-	-	-	-	-	-	-	++	-	-	-
		160.	*Citrus lemon* Burm.	-	-	-	-	-	-	-	++	-	-	-
51	Santalaceae	161.	*Santalum album* Linn.	+	-	-	-	-	-	-	-	-	-	-
		162.	*Litchi chinensis* Soun.	+	-	-	-	-	-	-	-	-	-	-
52	Sapotaceae	163.	*Manilkara sapota* (Linn.) Royen.	+	-	-	-	-	-	-	-	-	-	-
		164.	*Mimusops elengi* Linn.	+	-	-	-	-	-	-	-	-	-	-
53	Scorphalariaceae	165.	*Russelia sarmentosa* Jacq.	+	-	-	-	-	-	-	-	-	-	-
54	Solanaceae	166.	*Brunfelsia americana* Pohl.	+	-	-	-	-	-	-	-	-	-	-
		167.	*Capsicum frutescens* Linn.	-	-	-	-	-	-	-	++	-	-	-
		168.	*C. annum* Linn.	-	-	-	-	-	-	-	++	-	-	-
		169.	*Solanum melongena* Linn.	-	-	-	-	-	-	-	++	-	-	-
55	Sterculiaceae	170.	*Helicteres isora* Linn.	+	-	-	-	-	-	-	-	-	-	-
		171.	*Pterospermum acerifolium* Willd.	+	-	-	-	-	-	-	-	-	-	-

Sl. No.	Family	Sl. No.	Species	UC								KS	CB	GC
				BG	SF	AP	GL	CP	BB	PF	AG			
56	Theaceae	172.	*Camellia sinensis* (Linn.) Kuntz.	+	-	-	-	-	-	-	-	-	-	-
		173.	*C. thea* Link.	+	-	-	-	-	-	-	-	-	-	-
57	Theophrastaceae	174.	*Jacquinia ruscifolia* Jacq.	+	-	-	-	-	-	-	-	-	-	-
58	Rutaceae	175.	*Acronychia panduculata* (Linn.) Miq.	+	-	-	-	-	-	-	-	-	-	-
		176.	*Murraya paniculata* Linn.	+	-	-	-	-	-	-	-	-	-	-
59	Verbenaceae	177.	*Callicarpa americana* Linn.	+	-	-	-	-	-	-	-	-	-	-
		178.	*Cleorodendrum viscosum* Linn.	-	++	-	-	-	-	-	-	+	-	-
		179.	*C. inerma* (Linn.) Gaertn.	+	+	-	-	-	-	-	-	-	-	+
		180.	*Duranta repens* Linn.	+	-	-	-	-	-	-	-	-	-	-
		181.	*Stachy tarpheta mutabilis* (Jacqub) Vahl.	+	-	-	-	-	-	-	-	-	-	-
		182.	*Tectona grandis* Linn.	-	-	-	-	-	-	-	-	-	-	+
60	Cucurbitaceae	183.	*Cucurbita maxima* Duch.	-	-	-	-	-	-	-	++	-	-	-
		184.	*Cucumis sativus* Linn.	-	-	-	-	-	-	-	++	-	-	-
		185.	*Benincasa cerifera* Savi.	-	-	-	-	-	-	-	++	-	-	-
		186.	*Trichosanthus anguina*. Linn.	-	-	-	-	-	-	-	++	-	-	-
		187.	*Momordica charantia*. Linn.	-	-	-	-	-	-	-	++	-	-	-
61	Graminae	188.	*Eleusine indica* Linn.	-	-	-	+++	-	-	-	-	-	-	-
		189.	*Ischaemum* sp. Linn.	-	-	-	+++	-	-	-	-	-	-	-
		190.	*Bamboosa arundinacea* Willd.	-	-	-	-	-	+++	-	-	-	-	-
		191.	*Oryza sativa* Linn.	-	-	-	-	-	-	+++	-	-	-	-
		192.	*Spinefex littoreus* Linn.	-	-	-	-	-	-	-	++	-	+++	-
62	Dioscoreaceae	193.	*Dioscorea alata* Linn.	-	-	-	-	-	-	-	++	-	-	-

+ indicates presence ++ moderate presence +++ abundance - absence

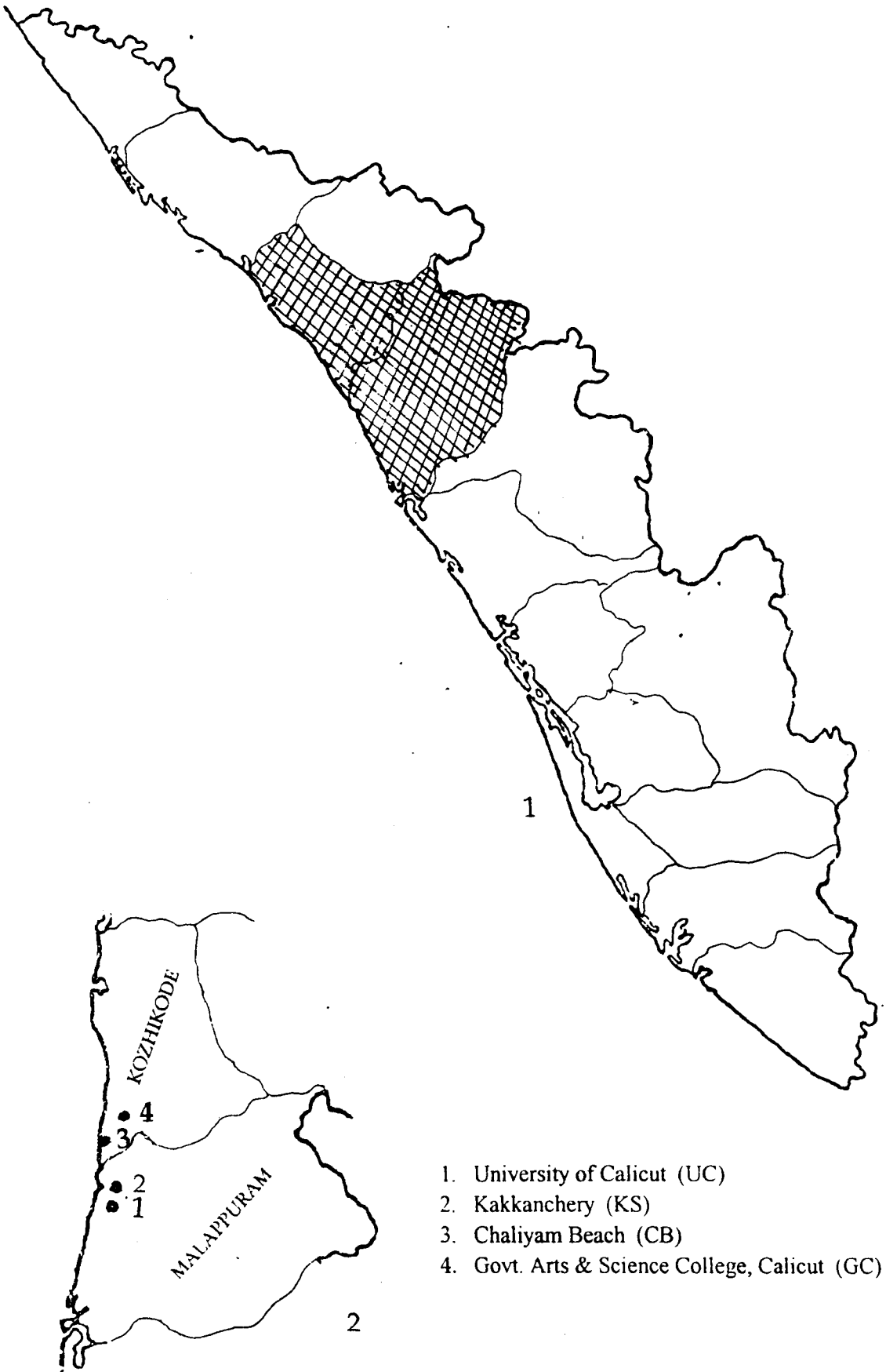
PLATE 6

Map of Kerala Showing Study Sites

Fig. 1 Map of Kerala

Fig. 2 Enlarged view of Kozhikode and Malappuram districts

PLATE 6



1. University of Calicut (UC)
2. Kakkanchery (KS)
3. Chaliyam Beach (CB)
4. Govt. Arts & Science College, Calicut (GC)

PLATE 7

Area Surveyed

Fig. 1 Botanical Garden

Fig. 2 Secondary Forest

Fig. 3 Acacia Plantation

Fig. 4 Grass Land

Fig. 5 Cashew Plantation

Fig. 6 Bamboo Grove

PLATE 8

Area Surveyed

Fig. 1 Paddy Field

Fig. 2 Agricultural Garden

Fig. 3 Kakkanchery Site

Fig. 4 Chaliyam Beach , DW (Drift Wood)

Fig. 5 Government College

PLATE 9

Extraction Apparatus, Extracted And Mounted Oribatid Mites

Fig. 1 Berlese- Tullgren funnel series used for extraction of orbatid mites.

Fig. 2 Closer view of single extraction unit: H-Heat source, S- Sample container, F- Funnel, C- Collecting vial

Fig. 3 A view of extracted oribatid mites

Fig. 4 Mounted view of *Atropacarus (Hoplophorella) chaliensis* sp. nov.

Fig. 5 Mounted view of *A (H.) crenulus* sp. nov.

Fig. 6 Mounted view of *A (H.) keralensis* sp. nov.

PART I
OBSERVATION

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

OBSERVATION

1. Species Density and Diversity of Oribatid Mites in the Four Study Sites

Field survey carried out during the present study yielded a rich and diverse population of oribatid mites. This helped to provide substantial information on the general pattern of distribution exhibited by oribatid mites in the selected areas. Predominance of these mites in three out of the four study sites indicated their numerical abundance and species diversity in edaphic ecosystems. The third study site viz., the Chaliyam Beach, harboured almost an equal proportion of collembola with that of mites. The survey yielded a total of 58 species belonging to 21 genera under 11 families and nine superfamilies (Tables 2 and 3).

Out of the 58 species identified, 38 or 65.5% belonged to Oribatei Inferiores and the remaining 20 or 34.5% to Oribtei Superiores. Inferior oribatids were represented by the members of four families viz., Apoplophoridae, Phthiracaridae, Lohmanniidae and Trhypochthoniidae. Of these, the family Lohmanniidae contributed the maximum generic composition with eight genera and 25 species. Phthiracaridae with three genera and eight species represented the second position while Trhypochthoniidae with two genera and four species formed the third position. Apoplophoridae showed the minimum generic representation as it included a single genus and a

single species. Thus the generic diversity of Oribatei Inferiores followed a descending order as follows:

Lohmanniidae > Phthiracaridae > Trhypochthoniidae > Apoplophoridae. Superior oribatids collected belonged to seven families viz., Basilobelbidae, Otocepheidae, Oppiidae, Schleoribatidae, Haplozetidae, Xylobatidae and Galumnidae. Each of these families were represented by a single genus. Scheloribatidae and Galumnidae with seven species each had the maximum species diversity, followed by Oppiidae with two species and the remaining four families with a single species each. Thus the species representation of the Oribatei Superiores recovered during the study could be presented as:

Galumnidae=Scheloribatidae>Oppiidae>Basilobelbidae= Otocepheidae=Haplozetidae=Xylobatidae.

The survey revealed that two higher oribatid genera viz., *Galumna* and *Scheloribates* formed the first in terms of species diversity, accommodating seven species each. Six species each of the lower oribatid genera *Atropacarus* (*Hoplophorella*), *Annectacarus* and *Haplacarus* could be collected from the different sites. The lohmanniid genus *Javacarus* was represented by four species. This was followed by two of the lower oribatid genera viz., *Cryptacarus* and *Allonothrus* which were represented by three species each. Two lower oribatid genera viz., *Vepracarus* and *Papillacarus* and a single higher oribatid genus, *Oppia* consisted of two species each. The remaining 10 genera i.e., six of the lower and four of the higher oribatids were represented by a single species each. These were *Apoplophora, Phthiracarus, Hoplophthiracarus,*

Heptacarus, Meristacarus, Archegozetes, Basilobelba, Megalotocepheus, Pelokylla and *Xylobates*. Plate 11 provides a comparison of the 21 genera while plate 12 gives a comparison of the 11 oribatid families studied.

Observations on the quantitative and qualitative distribution pattern of the various oribatid taxa showed distinct variation corresponding to the geographical and floral peculiarities of the sites surveyed (Table 2). Calicut University Campus (UC) with its rich floral composition and varied microhabitat conditions yielded 44 species of oribatid mites belonging to 18 genera, 11 families and nine superfamilies. These species were not found exhibiting a uniform distribution pattern in the various sites of the campus. Species diversity was comparatively high in the Botanical Garden (BG) which yielded 33 species belonging to 16 genera, 10 families and nine superfamilies and Secondary Forest (SF) from where 32 species belonging to 15 genera, nine families and eight superfamilies could be collected. Bamboo Grove (BB) was found supporting 28 species, cashew plantation (CP) 20, Acacia Plantations (AP) 17, Grass Land (GL) 16, Agricultural garden (AG) 12 and Paddy Field (PF) five.

The second study site from Kakkanchery (KS) also supported a rich oribatid population as 37 species belonging to 17 genera, eight families and seven superfamilies were represented here. The Campus of Government Arts and Science College (GC), Calicut which formed the fourth study site harboured 22 species of oribatid mites grouped under 12 genera, seven families and six superfamilies. The Chaliyam Beach (CB) which was the third study site, yielded the minimum number of

species. The oribatid population of this site consisted of 14 species belonging to six genera, six families and five superfamilies. Species diversity of oribatid mites in this site although was low, population density of the species recovered was rather high, especially that of the new taxa viz., *H. indicus* sp. nov and *A.* (*H.*) *chaliensis* sp. nov., particularly during monsoon season. A comparison of species diversity of oribatids from the four sites is presented in Plate 13. The study thus showed that the species diversity of oribatid mites in the different study sites decreased in the order KS>BG>SF>BB>GC>CP>AP>GL> CB>AG>PF.

The density of oribatid population recovered from the various sites also exhibited wide variation as evidenced from Table 4 and Plate-14. 66.28% of the total oribatid mites collected was contributed by the eight different sites located in the Calicut University Campus. Individual contribution by these different sites was as follows- BG-10.64%, SF-11.57%, AP-8.41%, GL-5.64%, CP-9.23%, BB-10.97%, PF-4.15% and AG-5.44%. The percentage contribution of the other three sites was as follows KS-13.76, CB-10.4 and GC-9.54. Thus the population density of oribatid mites in the different study sites decreased in the following order KS>SF>BB>BG>CB>GC>CP>AP>GL>AG>PF.

The maximum species diversity was exhibited by the primitive oribatid family Lohmanniidae which consisted of eight genera and 25 species. The Chaliyam Beach soil was found unsuitable for majority of lohmanniid mites as this site was represented only by a new species viz., *H. indicus*. The genus *Annectacarus* was represented by six species, of

which two were new to science. *A. wallworki* was recovered from sites BG, SF, CP, BB, KS and GC. *A.mucronatus* and *A. mahabaeus* could be collected from BG, SF and BB while *A. aokii* from BG, SF and CP. The site AP harboured the new species *A.malabaricus* while the other new member of the genus, *A. plumosus* was obtained from site GC. In short *A. wallworki* was common to sites, UC, KS and GC. *A. mucronatus, A. mahabaeus, A. aokii* and *A. malabaricus* were restricted to site UC and *A. plumosus* to site GC. The genus was completely absent in sites GL, PF, AG and CB.

The genus *Haplacarus* was also represented by six species, of which two appeared to be new to science. This genus could be collected from three out of the four sites. *H. pairathi* was the most abundant species which could be recovered from sites BG, AP, GL, CP, BB, KS and GC. *H. keralensis* was harboured by BG, SF, CP, BB and KS, *H. foliatus* by SF, BB and KS and *H.porosus* by SF and KS. *H. xavieri* was restricted to site BG and *H. davisi* to site KS. Thus a single species viz., *H. pairathi* was present in sites UC, KS and GC, three species viz., *H. porosus, H. foliatus* and *H. keralensis* in site UC and KS, *H. xavieri* in site UC and *H. davisi* in site KS, the last two species were newly described. This genus could not be detected in sites PF, AG and CB.

The genus *Javacarus* with four species occupied the second position in terms of species diversity. *J. reticulatus* was collected from sites BG, SF, KS and GC. *J. kuhnelti* was present in sites SF, AG, KS and GC. *J. kuhnelti foliatus* was recovered from sites BG, SF, DB, KS and GC. *J.*

minutus was detected in sites BG and SF and formed a new addition to the genus. Sites AP, GL, CP, PF and CB did not harbour this genus.

The genus *Cryptacarus* was represented by three species. *C. grandjeani* and *C. polysetosus* could be recovered from sites UC and KS while *C. dendrisetosus* was characteristic to site KS. *C. grandjeani* was obtained from BG, SF, CP and BB and *C. polysetosus* from SF alone. Population density of this genus was higher in site KS as all the three species were represented here. Two genera viz., *Vepracarus* and *Papillacarus* were represented by two species each. Both species of *Vepracarus* recovered turned out to be new to science, of which *V. ramaniae* was collected from site KS while the other, *V. arboriformes* from site BB. *P. undirostratus* was found in sites BG, SF, BB and GC while *P. elongatus* was a new discovery from site KS.

Two genera viz., *Heptacarus* and *Meristacarus* were represented by a single species each. *H. indicus* as already mentioned, was the only lohmanniid member that could be retrieved from CB where it was abundant in the decomposing drift wood. The genus *Meristacarus* consisted of a single species viz., *M. degradatus* which occurred in plenty among the decomposing leaf litter of site KS to which it was restricted. The study thus showed that the site UC had the richest lohmanniid population comprising six out of eight genera and 18 species. The genera *Meristacarus* and *Heptacarus* were absent here. Site KS harboured seven genera but only 15 species, *M. degradatus* was the most important species in this habitat. The genus *Heptacarus* was not represented here. Site GC supported seven species belonging to four genera. Site CB was

remarkable in that *H. indicus* was the only lohmanniid mite that could be retrieved from here.

The phthiracarid family was represented by three genera and eight species of which six belonged to the genus *Atropacarus* (*Hoplophorella*) and a single species each to *Phthiracarus* and *Hoplophthiracarus*. *A. (H.) scapellata* was collected from sties GL, CP, BB, AG, KS and GC. *A. (H.) keralensis* from BG, *A. (H.) reticulatus* from site SF and *A. (H.) chaliensis* and *A. (H.) crenulus* from site CB. The last mentioned four species were new additions to the genus. *P. haqi* collected from site KS also proved to be new to science. *H. regalis* appeared to enjoy a fairly good distribution trend in sites BG, SF, AP, GL, CP, BB, KS and GC. Thus five out of the eight species were present in different parts of the study site UC. Site KS harboured three species while CB and GC two species each. Site PF did not harbour any phthiracarid mites. The study yielded five new species of phthriacarid mites, two each from sites UC and CB and one from site KS.

The next important lower oribatid genus collected during the present study was that of the family Trhypochthoniidae viz., *Allonothrus* which was represented by three species. *A. russeolus* was recovered from sites BG, SF, CP, BB, KS, and GC, *A. monodactylus* from BG, AP, KS and GC and *A. giganticus* from BG, SF, AP, BB, KS and GC. The sites GL, PF, AG and CB were completely devoid of the genus.

The remaining two lower oribatid genera viz., *Apoplophora* and *Archegozetes* were represented by a single species each. *A. pantotrema* was obtained from sites BG, SF, GL, BB, KS and GC. *A. longisetosus* was

present in all the sites and its density was particularly high in the Chaliyam Beach soil especially during the monsoon season.

In the matter of species diversity among the higher oribatids, two genera viz., *Galumna* and *Scheloribates* were most versatile with seven species each. *G. flabellifera* occurred in plenty in sites BG, SF, AP, GL, CP, BB, KS and CB, but was absent in sites PF, AG and GC. *G. obvia* could be collected from sites PF, AG, KS and GC. *G. discifera* was detected in sites BG, SF, AP, GL CP, BB and KS while *G. triquetra* occurred in GL and CB. A characteristic feature of sites KS, CB and GC was the presence of one particular species of the genus which was harboured by that site alone ie., *G. chujoi*, *G. alata* and *G. longipluma* respectively. The sites UC and KS thus harboured maximum number of this genus with four species each, CB three species and GC two species. *G. obvia* was the only galumnoid mite that could be collected from sites PF and AG.

The genus *Scheloribates* exhibited a higher population density when compared to that of the genus *Galumna*. All the seven species viz., *S. laevigatus*, *S. latipes*, *S. praeincisus*, *S. rectus*, *S. cuyi*, *S. decarinatus* and *S. minuta* were present in site KS. Of these, *S. cuyi* was a unique species found only in this site. Site CB harboured five species and *S. cuyi* and *S. rectus* were absent here. Four species viz., *S. laevigatus*, *S. praeincisus*, *S. decarinatus* and *S. minuta* could be collected from site GC. The different habitats of site UC together yielded six out of the seven species, *S. cuyi* being absent. All these six species were present in BG, while sites SF, AP, GL, CP, BB and AG harboured five species, *S. rectus* being absent, while *S. minuta* was the single representative of this genus in site

PF. Thus the study revealed the presence of *S. minuta* in all the areas selected.

The higher oribatid genus *Oppia* consisted of two species viz. *O. neerlandica* and *O. kuhnelti*. A remarkable feature of this genus was that the two species were well represented in all the four sites, except that the former species was absent in sites PF and AG. The remaining four higher oribatid genera, viz., *Basilobelba, Megalotocepheus, Pelokylla* and *Xylobates* were represented by a single species each. *B. retiarius* was collected from sites BG, SF and AP. *M. glabrus* recovered from site BG turned out to be new to science. *P. malabarica* was restricted to site BB. *X. seminudus* was present in all the sites of UC and site KS and completely absent from sites CB and GC.

Thus, of the 44 species of oribatid mites recorced from site UC, 13 species viz., *A. (H) singularis, A. (H) reticulatus, A. (H) keralensis, A. mucronatus, A. mahabaeus, A. aokii, A. malabaricus, H. xavieri, J. minutus, V. arborifomes, B. retiarius, M. glabrus* and *P. malabarica* were unique to this site. Seven species viz., *A. (H) reticulatus, A. (H) keralensis, A. malabaricus, H. xavieri, J. minutus, V. arboriformes* and *M. glabrus* turned out to be new to science.

Of the 37 species collected from site KS, eight species viz., *P. haqi, C. dendrisetosus, H. davisi, V. ramaniae, P. elongatus, M. degradatus, S. cuyi* and *G. chujoi* were restricted to this site alone. Four species viz., *P. haqi, H. davisi, V. ramaniae* and *P. elongatus* were new additions to science.

Four out of the 14 species viz., *A. (H.) chaliensis A. (H.) crenulus, H. indicus* and *G. alata* collected from site CB were unique to that site and

except the last, the other three were found to be new to science. The unique species of the site GC were *A. plumosus* and *G. longipluma* of which the former formed a new taxon.

Thus the study yielded 15 new species belonging to three families of Phthiracaridae, Lohmanniidae and Otocepheidae. *A. (H.) chaliensis, A. (H.) reticulatus, A. (H.) keralensis, A. (H.) crenulus and P. haqi* belonged to *Phthiracaridae, A. malabaricus, A. plumosus, H. xavieri, H. davisi, P. elongates, V. arboriformes, V. ramaniae, J. minutus* and *H. indicus* belonged to Lohmanniidae and *M. glabrus* to Otocepheidae. 25.9% of the total oribatid mites collected thus turned out to be new species, of which 93.3% belonged to lower oribatids and 6.7% belonged to higher oribatid family Otocepheidae. Among the lower oribatids, the family Phthiracaridae contributed 33.3% and the remaining 60% belonged to Lohmanniidae (Plate-15).

2. Morphological Peculiarities and Behavioural Patterns of Oribatid Mites

The morphological peculiarities and behavioural patterns of the various oribatid mites collected were quite interesting. Members of Phthiracaridae and Trhypochthoniidae were highly lethargic in habit. Lohmanniidae which represented the family with maximum species diversity consisted of oribatid mites which were sluggish and rather slow in movement. The most primitive member *A. pantotrema* was remarkable in its activity and movement while members of *A. longisetosus* were quite often seen aggregating in a peculiar manner

forming a rosette. The various species of *Allonothrus* were moderately active.

Members of Phthiracaridae possessed well sclerotised body ranging in colour from creamy white to golden yellow. Lohmanniids possessed moderately sclerotised body as exhibited by members of *Annectacarus, Javacarus, Haplacarus, Heptacarus, Papillacarus* and *Vepracarus* to well sclerotised body of *Meristacarus,* the colour of which varied from golden yellow to dark brown, depending upon the extent of sclerotisation. Sclerotisation was almost absent in *Archegozetes* which appeared pale white in colour. Mesoplophoridae had moderately sclerotised body while various species of *Allonothrus* possessed well sclerotised body with a dirty black colour.

Members of the Oribatei Superiores studied during the present investigation possessed well sclerotised body in various degrees. The Haplozetid, Xylobatid and Galumnid members were characterised by their large, globular to oval body with a dark brown or black texture and their very active nature. Members of Oppiidae were rather minute, more or less oval with slender, weakly sclerotised body but were specific for their fastidious habits. Members of Scheloribatidae were very active and possessed broad spherical body. Basilobelbidae was characterised by the presence of the moulting skin which remained attached to the back of the body. Members of Otocepheidae were fairly large sized oribatid mites with well sclerotised oblong black coloured body.

3. Influence of Rainfall and Temperature on Oribatid Mite Population

An attempt was made during the present study to assess the seasonal variations in the oribatid population density with reference to rainfall and temperature. Table 4 and plate-16 provide data on monthly variations in the number of oribatid mites collected for a period of one year from September, 2001 to August, 2002. Maximum number of oribatid mites were collected during the monsoon months of June, July and August with slight variations in the four different sites. Number of oribaitd mites collected from all the sites of UC during the months of June, July and August were 582, 493 and 566. KS site yielded 120, 95 and 112 mites during the same period. Site CB yielded 113, 104 and 108 and site GC 74, 56 and 68 respectively. Thus the maximum number of oribatid mites was collected in June from all the sites under study. Similarly the minimum collection of oribatid mites was obtained during the summer months of February, March and April. Oribatid mites collected during the above three months from the four different study sites were 140, 102 and 127; 37, 27 and 33; 12, 10 and 8 and 20, 18 and 22 respectively. Data on monthly rainfall and temperature during the same period are presented in Tables 5 and 6 and plates 17 and 18 respectively. The month of June received the maximum rain of 568.2, 573.7, 564.9 and 572.1mm respectively in sites UC, KS, CB and GC followed by May which received 480.2, 490.4, 483.6 and 478.6mm and August with 469.6, 458.3, 473.8 and 464.7mm in the respective sites. There was practically no rain during December, January and February. The month of March received a minimum of 32, 29.7, 36.8 and 34.2mm of rain and experienced the highest temperature of 37.5, 37.6, 37.4 and 37.3^{0}C

respectively in sites UC, KS, CB and GC. The minimum temperature of 29.2, 29, 29.3 and 29°C was experienced during the month of June in the respective sites. From the table it could be noticed that the month of June which received the maximum rain experienced the minimum temperature while the month of March with the minimum rain experienced the maximum temperature. The months of December, January and February though received no rain the temperature was slightly lower than that in March. An analysis of these data showed that oribatid populations exhibited an increase during rainy season and decrease in summer season when there was practically no rain and the atmospheric temperature was quite high. In short, the maximum number of oribatid mites were collected in the month of June which received the maximum rain and experienced the minimum temperature. The significance of these observations were statistically analysed by calculating the correlation coefficient 'ϒ' in respect of population density against rainfall and temperature from the four different sites. Correlation coefficient between population density and rain fall in sites UC, KS, CB and GC were 0.68, 0.66, 0.76 and 0.78 respectively. Correlation coefficient between population density and temperature in the four sites were found to be -0.90, -0.92, -0.90 and -0.87 respectively. Table 7 provides the consolidated data revealing the existence of a definite positive correlation between rainfall and population density of oribatid mites and a negative correlation between temperature and mite population.

Table 2 - Distribution of Oribatid mites collected from the four study sites

Sl. No.	Oribatid mite species	UC								KS	CB	GC
		BG	SF	AP	GL	CP	BB	PF	AG			
1	*Apoplophora pantotrema* Berlese, 1913	++	++	-	+	-	++	-	-	++	-	+
2.	*Atroparacarus (Hoplophorella) singularis* Sellnick, 1959	+	+	-	-	+	+	-	+	-	-	-
3	*H. (H.) scapellata* Aoki, 1965	-	-	-	+	+	+	-	+	++	-	+
4	*A. (H.) chaliensis* sp. nov.	-	-	-	-	-	-	-	-	-	+++	-
5	*A. (H.) crenulus* sp. nov.	-	-	-	-	-	-	-	-	-	++	-
6	*A. (H.) reticulatus* sp. nov.	-	++	-	-	-	-	-	-	-	-	-
7	*A. (H.) keralensis* sp. nov.	++	--	-	-	-	-	-	-	-	-	-
8	*Phthiracarus haqi* sp. nov.	-	-	-	-	-	-	-	-	+++	-	-
9	*Hoplophthiracarus regalis* Mahunka, 1978	+	+	+	+	+	+	-	-	++	-	+
10	*Annectacarus mucronatus* Grandjean, 1950	+	+	-	-	-	+	-	-	-	-	-
11	*A. mahabaeus* Corpuz Raros, 1979	+	+	-	-	-	+	-	-	-	-	-
12	*A. wallworki* Clement and Haq, 1989	+	+	-	-	+	+	-	-	+	-	+
13	*A. aokii* Jaikumar *et al.* 1994	+	+	-	-	+	-	-	-	-	-	-
14	*A. malabaricus* sp. nov.	-	-	++	-	-	-	-	-	-	-	-
15	*A. plumosus* sp. nov.	-	-	-	-	-	-	-	-	-	-	++
16	*Cryptacarus dendrisetosus* Bhattacharya *et al.* 1974	-	-	-	-	-	-	-	-	++	-	-
17	*C. polysetosus* Haq, 1976	-	+	-	-	-	-	-	-	+	-	-
18	*C. grandjeani* Clement and Haq, 1990	+	+	-	-	+	+	-	-	++	-	-
19	*Haplacarus foliatus* Wallwork, 1962	-	+	-	-	-	+	-	-	++	-	-
20	*H. pairathi* Aoki, 1965	+	-	+	+	+	+	-	-	++	-	+
21	*H. keralensis* Haq *et al.*, 1983	+	+	-	-	+	+	-	-	+	-	-

Sl. No.	Oribatid mite species	UC								KS	CB	GC
		BG	SF	AP	GL	CP	BB	PF	AG			
22	*H. porosus* Haq and Clement 1987	-	+	-	-	-	-	-	-	+	-	-
23	*H. xavieri* sp. nov.	++	-	-	-	-	-	-	-	-	-	-
24	*H. davisi* sp. nov.	-	-	-	-	-	-	-	-	++	-	-
25	*Heptacarus indicus* sp. nov.	-	-	-	-	-	-	-	-	-	+++	-
26	*Javacarus kuhnelti* Balogh, 1961	-	+	-	-	-	-	-	+	+	-	+
27	*J. kuhnelti foliatus* Hammer, 1972	+	+	-	-	-	+	-	-	+	-	+
28	*J. reticulatus* Sengbusch, 1982	++	+	-	-	-	-	-	-	+	-	+
29	*J. minutus* sp. nov.	+	++	-	-	-	-	-	-	-	-	-
30	*Vepracarus arboriformes* sp. nov.	-	-	-	-	-	+	-	-	-	-	-
31	*V. ramaniae* sp. nov.	-	-	-	-	-	-	-	-	+	-	-
32	*Meristacarus degradatus* Haq and Jaikumar, 1993	-	-	-	-	-	-	-	-	+++	-	-
33	*Papillacarus undirostratus* Aoki, 1965	+	+	-	-	-	+	-	-	-	-	+
34	*P. elongatus* sp. nov.	-	-	-	-	-	-	-	-	+	-	-
35	*Allonothrus russeolus* Wallwork, 1960	+	+	-	-	+	+	-	-	++	-	+++
36	*A. monodactylus* Wallwork, 1960	++	-	+	-	-	-	-	-	++	-	++
37	*A. giganticus* Haq, 1978	++	+	+	-	-	+	-	-	+	-	+
38	*Archegozetes longisetosus* Aoki, 1965	+	+	+	+	+	+	+	+	+	+++	+
39	*Basilobelba retiarius* Warburton, 1912	++	+	+	-	-	-	-	-	-	-	-
40	*Megalotocepheus glabrus* sp. nov.	++	-	-	-	-	-	-	-	-	-	-
41	*Oppia nearlandica* Oudemans, 1900	++	+	+	+	+	++	-	-	+++	+++	+
42	*O. kuhnelti* Aoki, 1965	++	++	+	+	+	++	+	+	++	++	++
43	*Scheloribates laevigatus* C. L. Koch, 1836	++	+	+	+	+	+	-	+	++	++	+
44	*S latipes* C L Koch, 1841	+	+	+	+	+	+	-	+	++	+	-

Sl. No.	Oribatid mite species	UC								KS	CB	GC
		BG	SF	AP	GL	CP	BB	PF	AG			
45	*S preincisus* Berlese, 1913	+	+	+	+	+	+	-	+	+++	++	+
46	*S. rectus* Hammer, 1958	+	-	-	-	-	-	-	-	+	-	-
47	*S. cuyi* Corpuz Raros, 1980	-	-	-	-	-	-	-	-	+	-	-
48	*S. decarinatus* Aoki, 1984	+	+	+	+	+	++	-	+	++	+++	+
49	*S. minuta* Mahunka, 1984	+	++	+	+	+	+	+	+	++	+	+
50	*Pelokylla malabarica* Clement and Haq, 1982	-	-	-	-	-	++	-	-	-	-	-
51	*Xylobates seminudus* Hammer, 1972	+	+	+	+	+	+	+	+	++	-	-
52	*Galumna alata* Hermann, 1804	-	-	-	-	-	-	-	-	-	++	-
53	*G. longipluma* Berlese, 1904	-	-	-	-	-	-	-	-	-	-	++
54	*G. obvia* Berlese, 1915	-	-	-	-	-	-	+	+	+	-	+
55	*G. discifera* Balogh, 1958	+	+	+	+	+	+	-	-	++	-	-
56	*G. flabellifera* Aoki, 1965	+	+	+	+	+	+	-	-	++	++	-
57	*G. triquetra* Aoki, 1965	-	-	-	+	-	-	-	-	-	+	-
58	*G. chujoi* Aoki, 1966	-	-	-	-	-	-	-	-	++	-	-
	Total no. of species recovered from each site	33	32	17	16	20	28	5	12	37	14	22

+ indicates presence ++ moderate presence +++ abundance - absence

Table 3 - Taxonomic position of oribatid mites collected from the four study sites

Super family	Family	Genus	Species
I. Group: Oribatei Inferiores or Macropylina			
1. Mesoplophoroidea Van Der Hammen, 1959	1. Mesoplophoridae Ewing, 1917	1. *Apoplophora* (Berlese, 1904)	1. *Apoplophora pantotrema* Berlese, 1913
2. Phthiracaroidea Grandjean, 1954	2. Phthiracaridae Perty, 1841	2. *Atropacarus* Eving, 1917 (*Hoplophorella* Berlese, 1923)	2. *Atropacarus (Hoplophorella) singularis* Sellnick, 1959 3. *A. (H.) scapellata* Aoki, 1965 4. *A. (H.) chaliensis* sp. nov. 5. *A. (H.) crenulus* sp. nov. 6. *A. (H.) reticulatus* sp. nov. 7. *A. (H.) keralensis* sp. nov.
		3. *Phthiracarus* Perty, 1839	8. *Phthiracarus haqi* sp. nov.
		4. *Hoplophthiracarus* Ramsay, 1966	9. *Hoplophtiracarus regalis* Mahunka, 1978
3. Lohmannoidea Grandjean, 1967	3. Lohmanniidae Berlese, 1916	5. *Annectacarus* Grandjean, 1950	10. *Annectacarus mucronatus* Grandjean, 1950 11. *A. mahabaeus* Corpus Raros, 1979 12. *A. wallworki* Clement and Haq, 1989 13. *A. aokii* Jaikumar *et al.*, 1994 14. *A. malabaricus* sp. nov. 15. *A. plumosus* sp. nov.
		6. *Cryptacarus* Grandjean, 1950	16. *Cryptacarus dendrisetosus* Bhattacharya *et al.*, 1974 17. *C. polysetosus* Haq, 1976 18. *C. grandjeani* Clement and Haq, 1990

Super family	Family	Genus	Species
		7. *Haplacarus* Wallwork, 1962	19. *Haplacarus foliatus* Wallwork, 1962 20. *H. pairathi* Aoki, 1965 21. *H. keralensis* Haq *et al.*, 1983 22. *H. porosus* Haq and Clement, 1987 23. *H. xavieri* sp. nov. 24. *H. davisi* sp. nov.
		8. *Heptacarus* Piffl, 1963	25. *Heptacarus indicus* sp.nov.
		9. *Javacarus* Balogh, 1961	26. *Javacarus kuhnelti* Balogh, 1961 27. *J. kuhnelti foliatus* Hammer, 1972 28. *J. reticulatus* Sengbusch, 1982 29. *J. minutus* sp. nov.
		10. *Vepracarus* Aoki, 1965	30. *Vepracarus arboriformes* sp. nov. 31. *V. ramaniae* sp. nov.
		11. *Meristacarus* Grandjean, 1934	32. *Meristacarus degradatus* Haq and Jaikumar, 1993
		12. *Papillacarus* Kunst, 1959	33. *Papillacarus undirostratus* Aoki, 1965 34. *P. elongatus* sp. nov.
4. Nothroidea Grandjean, 1954	4. Trhypochthoniidae Willmann, 1931	13. *Allonothrus* Vander Hammen, 1953	35. *Allonothrus russeolus* Wallwork, 1960 36. *A. monodactylus* Wallwork, 1960 37. *A. giganticus* Haq, 1978
		14. *Archegozetes* Grandjean, 1931	*38. Archegozetes longisetosus*, Aoki, 1965

Super family	Family	Genus	Species
II. Group: Oribatei Superiores or Brachypylina			
5. Eremuloidea Grandjean, 1965	5. Basilobelbidae Balogh, 1961	15. *Basilobelba* Balogh, 1958	39. *Basilobelba retiarius* Warburton, 1912
6. Otocepheoidea Balogh, 1972	6. Otocepheidae Balogh, 1961	16. *Megalotocepheus* Aoki, 1965	40. *Megalotocepheus glabrus* sp.nov.
7. Oppioidea Balogh, 1961	7. Oppiidae Grandjean, 1954	17. *Oppia* C. L Koch, 1956	41. *Oppia neerlandica* Oudemans, 1900 42. *O. kuhnelti* Aoki, 1965
8. Oribatuloidea Woolley, 1956	8. Scheloribatidae Balogh and Balogh, 1984	18. *Scheloribates Berlese*, 1908	43. *Scheloribates laevigatus* C. L. Koch, 1836 44. *S. latipes* C. L. Koch, 1841 45. *S. preincisus* Berlese, 1913 46. *S. rectus* Hammer, 1958 47. *S. cuyi* Corpuz Raros, 1980 48. *S. decarinatus* Aoki, 1984 49. *S. minuta* Mahunka, 1984
	9. Haplozetidae Grandjean, 1936	19. *Pelokylla* Clement and Haq, 1982s	50. *Pelokylla malabarica* Clement and Haq, 1982
	10. Xylobatidae Balogh and Balogh, 1984	20. *Xylobates* Jacot, 1929	51. *Xylobates seminudus* Hammer, 1972
9. Galumnoidea Balogh, 1961	11. Galumnidae Jacot, 1925	21. *Galumna* Von Heyden, 1826	52. *Galumna alata* Hermann, 1804 53. *G. longipluma* Berlese, 1904 54. *G. obvia Berlese*, 1915 55. *G. discifera* Balogh, 1958 56. *G. flabellifera* Aoki, 1965 57. *G. triquetra* Aoki, 1965 58. *G. chujoi* Aoki, 1966

Table 4 - Population density of Oribatid mites in the four study Sites From September, 2001 to August, 2002

Period	UC									KS	CB	GC
	BG	SF	AP	GL	CP	BB	PF	AG	Total			
Sept., 2001	47	51	37	36	42	48	24	27	312	61	48	52
Oct., 2001	42	47	32	22	38	44	22	18	265	57	52	68
Nov., 2001	56	52	48	40	40	52	25	30	343	62	42	57
Dec., 2001	55	56	41	40	34	54	18	28	326	66	38	40
Jan., 2002	45	50	32	23	40	48	17	23	278	60	25	29
Feb., 2002	25	27	14	10	16	29	8	11	140	37	12	20
Mar., 2002	16	17	12	8	14	15	7	13	102	27	10	18
Apr., 2002	19	23	15	10	16	19	9	16	127	33	8	22
May., 2002	48	49	29	20	35	45	18	20	264	59	36	43
June., 2002	92	102	78	46	88	96	34	46	582	120	113	74
July., 2002	75	89	68	36	80	85	24	36	493	95	104	56
Aug., 2002	90	100	76	44	86	94	32	44	566	112	108	68
Total	**610**	**663**	**482**	**335**	**529**	**629**	**238**	**312**	**3798**	**789**	**596**	**547**
Percentage	**10.64**	**11.57**	**8.41**	**5.84**	**9.23**	**10.97**	**4.15**	**5.44**	**66.28**	**13.76**	**10.40**	**9.54**

Table 5 - Monthly Rainfall in the Four Study Sites From September, 2001 to August, 2002

Period	Rainfall in mm in the Four Study Sites			
	UC	KS	CB	GC
September, 2001	255.6	228.1	240.2	232.0
October, 2001	350.4	345.6	356.1	352.4
November, 2001	118.6	120.5	115.7	122.3
December, 2001	0	0	0	0
January, 2002	0	0	0	0
February, 2002	0	0	0	0
March, 2002	32.0	29.7	36.8	34.2
April, 2002	97.0	98.0	94.1	95.5
May, 2002	480.2	490.4	485.6	478.6
June, 2002	568.2	573.7	564.9	572.1
July, 2002	303.7	305.4	300.7	308.3
August, 2002	469.6	458.3	473.8	464.7

Table 6 - Monthly temperature in the four study sites from September, 2001 to August, 2002

Period	Temperature in ^{0}C in the Four Study Sites			
	UC	KS	CB	GC
September, 2001	33.4	33.6	33.2	33.3
October, 2001	33.5	33.7	33.3	33.4
November, 2001	34.2	34.1	34.4	34.0
December, 2001	35.6	35.6	35.5	35.7
January, 2002	35.0	35.1	35.0	35.0
February, 2002	36.8	36.7	36.8	36.7
March, 2002	37.5	37.6	37.4	37.3
April, 2002	36.3	36.4	36.4	36.5
May, 2002	36.7	36.5	36.6	36.8
June, 2002	29.2	29.0	29.3	29.0
July, 2002	33.3	33.2	33.4	33.0
August, 2002	30.1	30.3	30.0	30.2

Table 7 - Correlation coefficient between population density, rainfall and temperature in the four study sites from September 2001 to August 2002

Site	Correlation coefficient r for			
	Rainfall	Nature of correlation	Temperature	Nature of correlation
UC	0.68	Positive	-0.90	Negative
KS	0.66	Positive	-0.92	Negative
CB	0.76	Positive	-0.90	Negative
GC	0.78	Positive	-0.87	Negative

PLATE 10

Mounted Oribatid Mites

Fig. 1 Mounted view of *Phthiracarus haqi* sp. nov.

Fig. 2 Mounted view of *Annectacarus malabaricus* sp. nov.

Fig. 3 Mounted view of *A. plumosus* sp. nov.

Fig. 4 Mounted view of *Javacarus minutus* sp. nov.

Fig. 5 Mounted view of *Vepracarus ramaniae* sp. nov.

Plate 11 - Composition of various genera of Oribatid mites in the four study sites from September, 2001 to August 2002

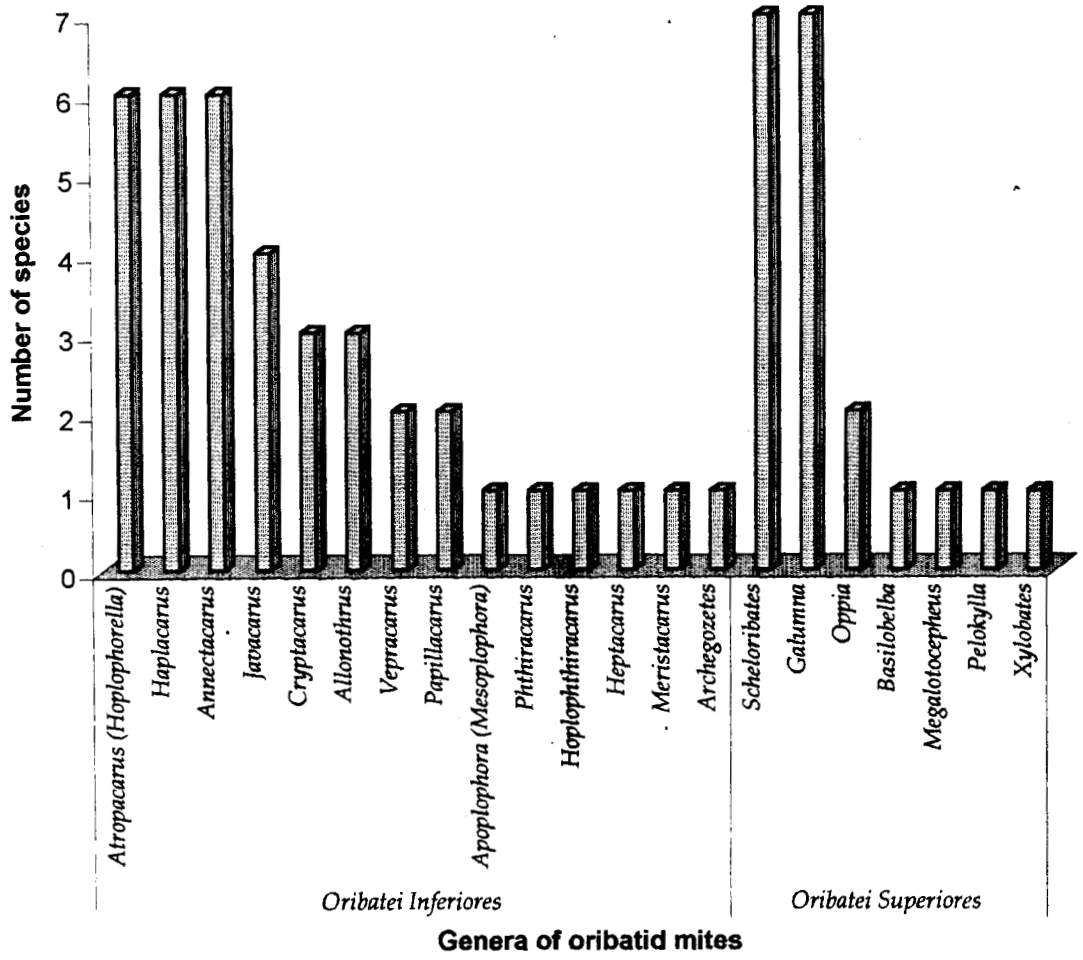


Plate 12 - Comparison of various oribatid families in the four study sites from September 2001, August 2002

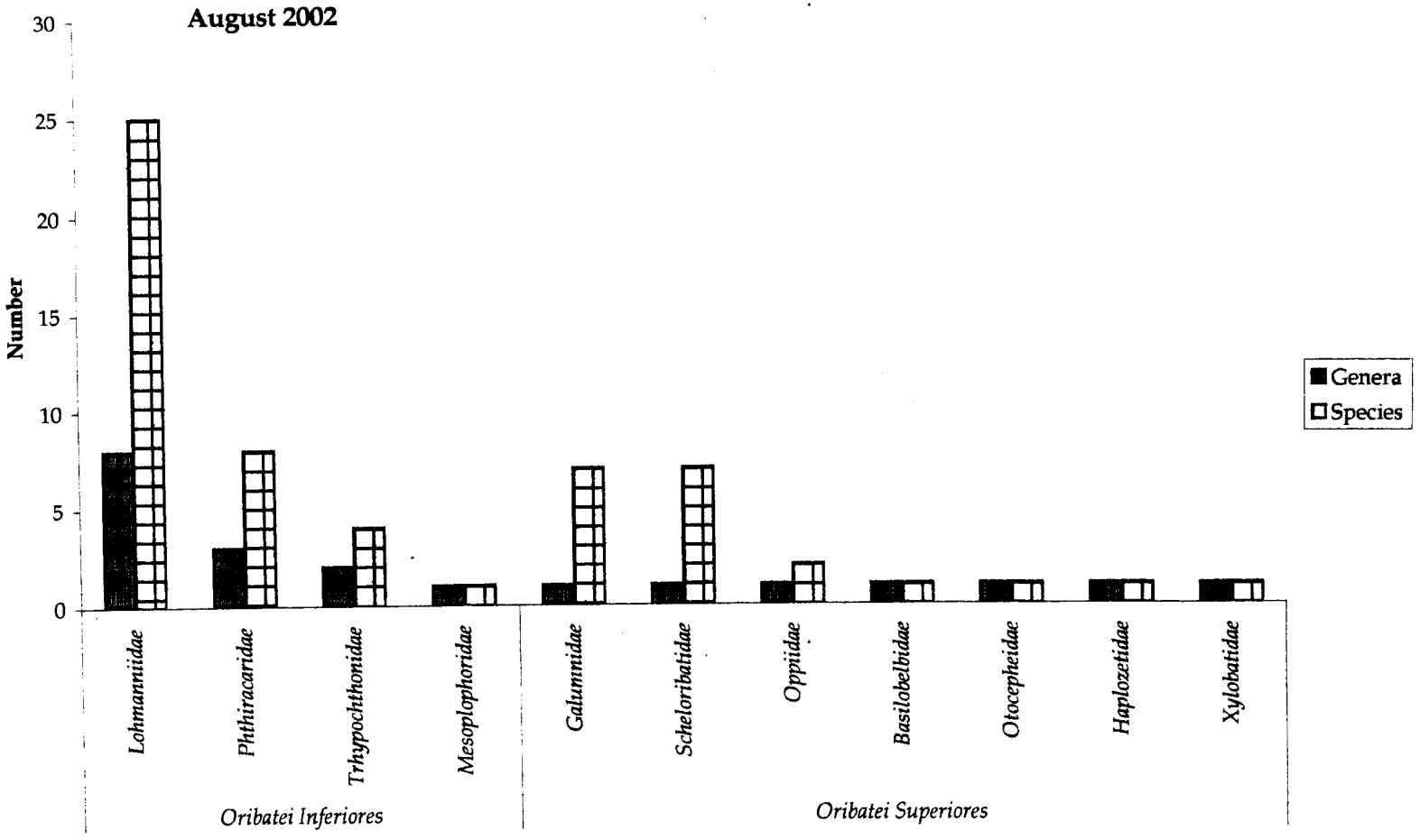


Plate 13 - Comparison of diversity of oribatid mites in the four study sites from September 2001 to August 2002

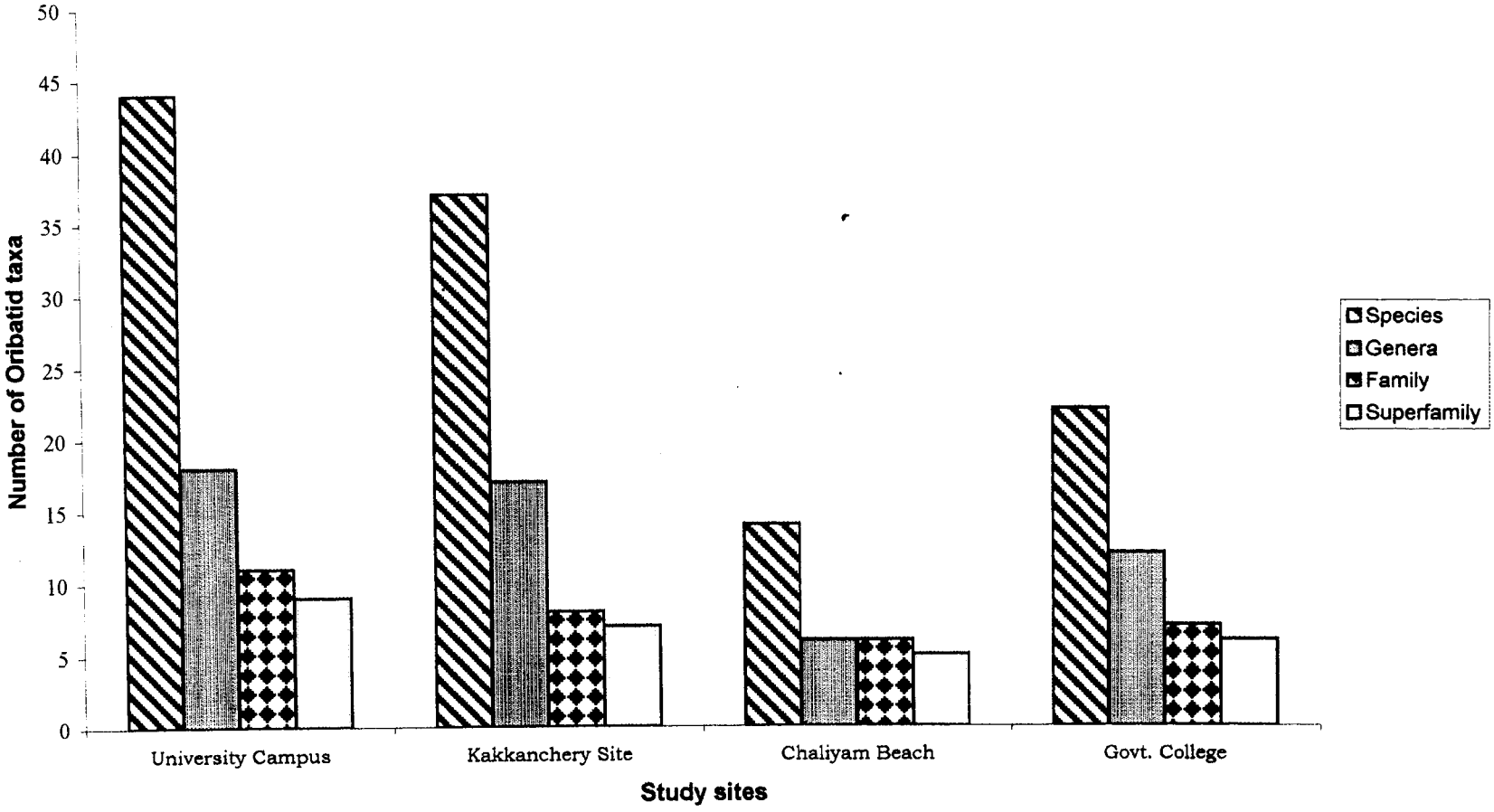


Plate 14 - Comparison of density of oribatid mites in the four study sites

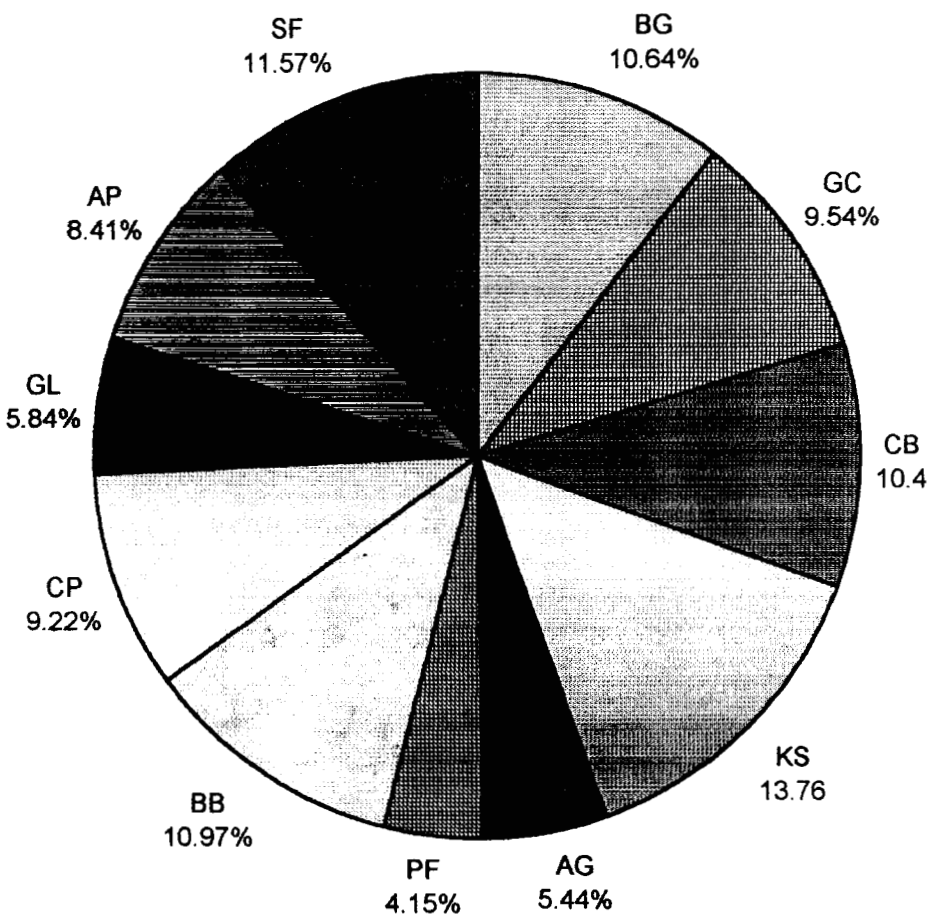


Plate 15 - Percentage distribution of new species

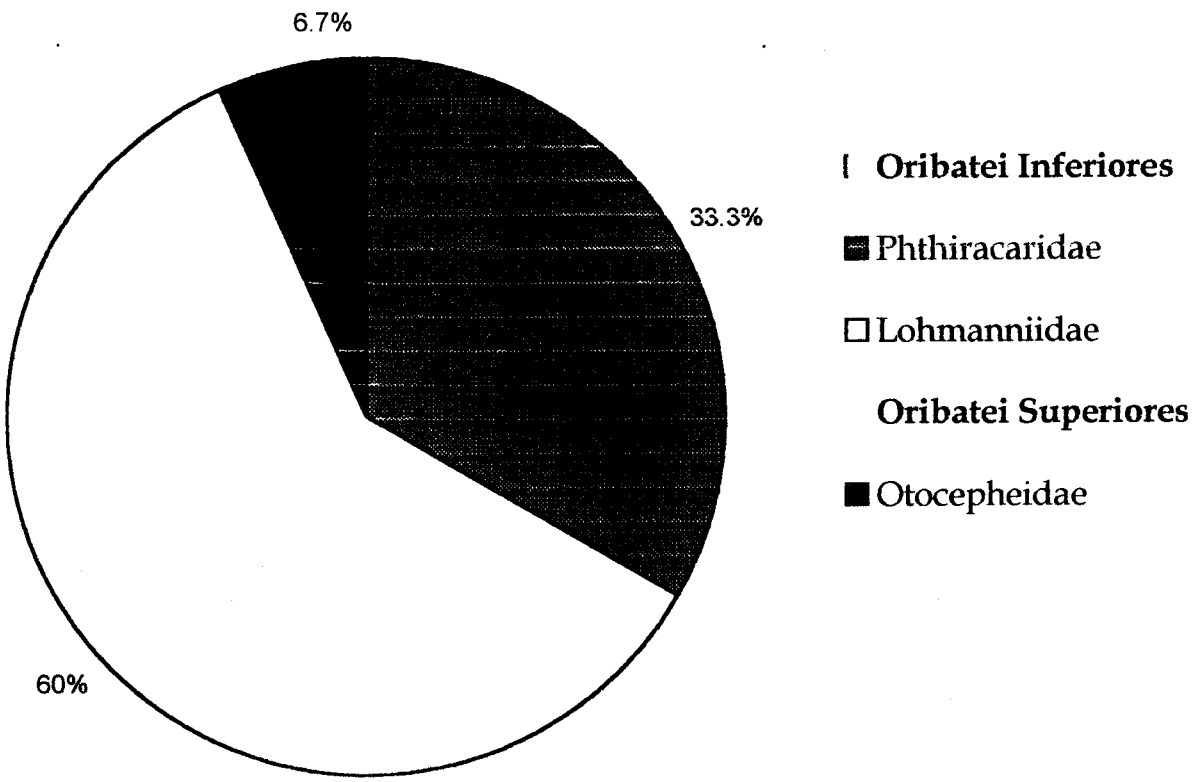


Plate 16 - Monthly variation in oribatid mite population density in the four study sites for 1 year from Sept., 2001 to Aug., 2002

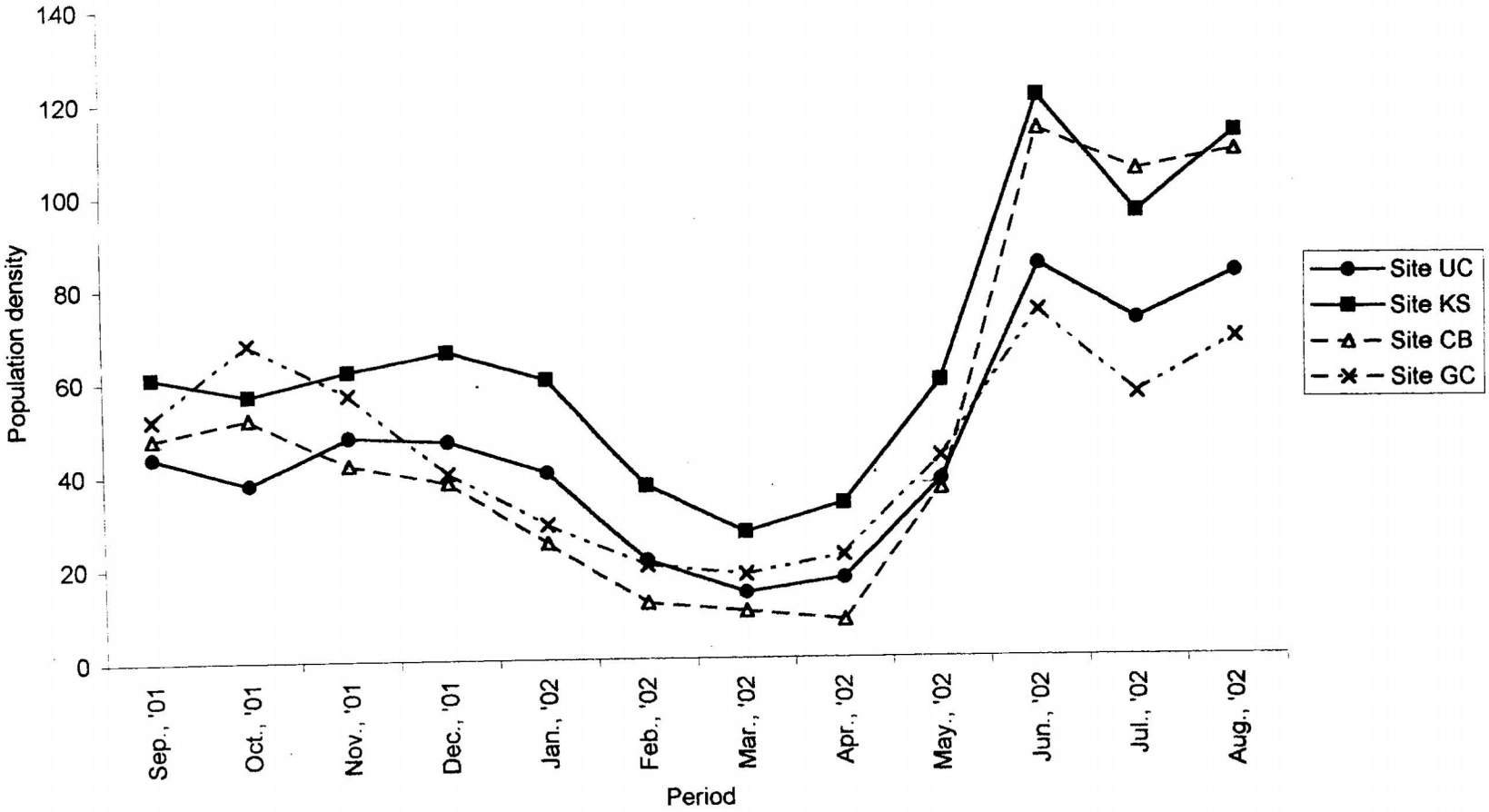


Plate 17 - Monthly rainfall in the four study sites for 1 year from Sept., 2001 to Aug., 2002

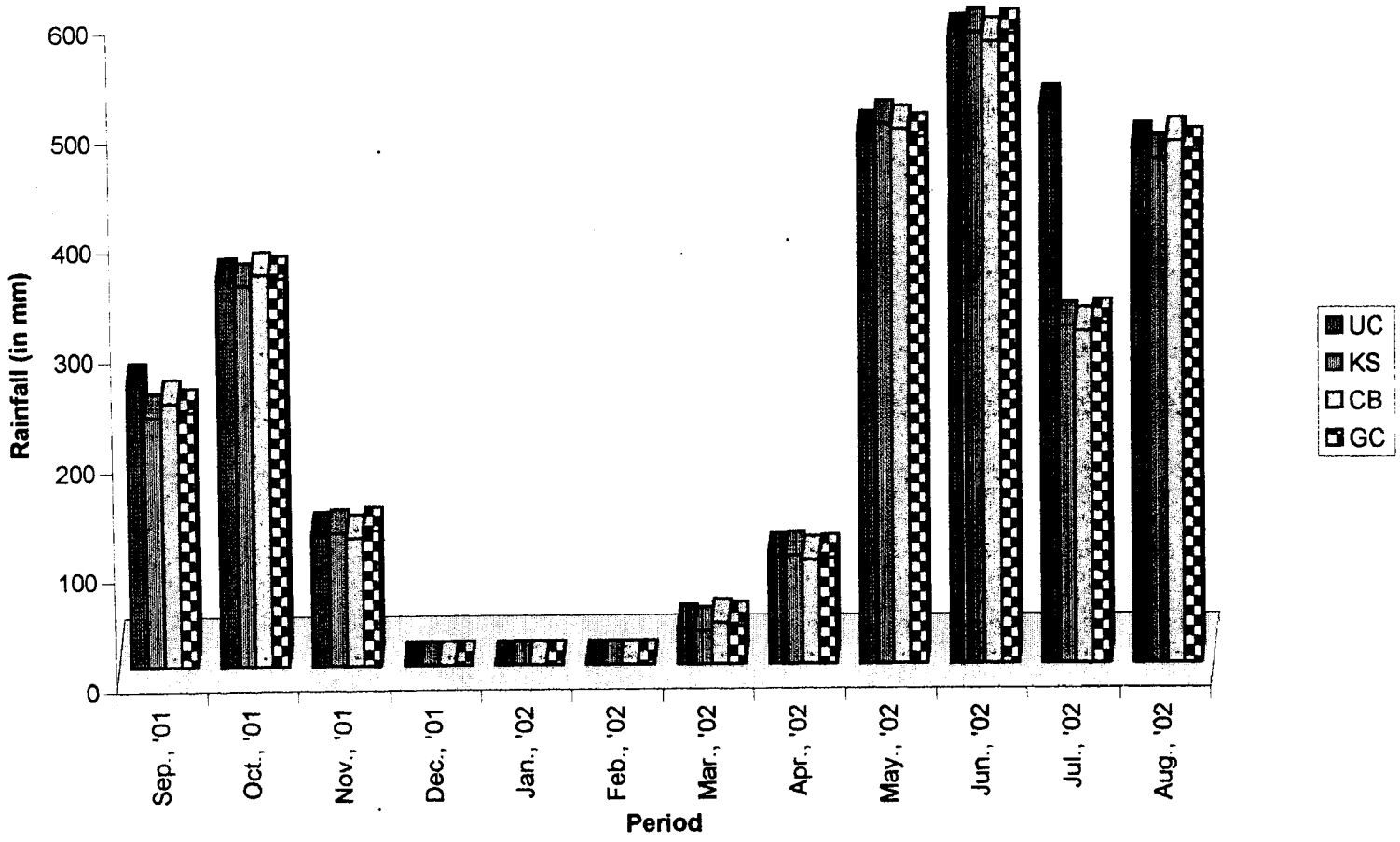
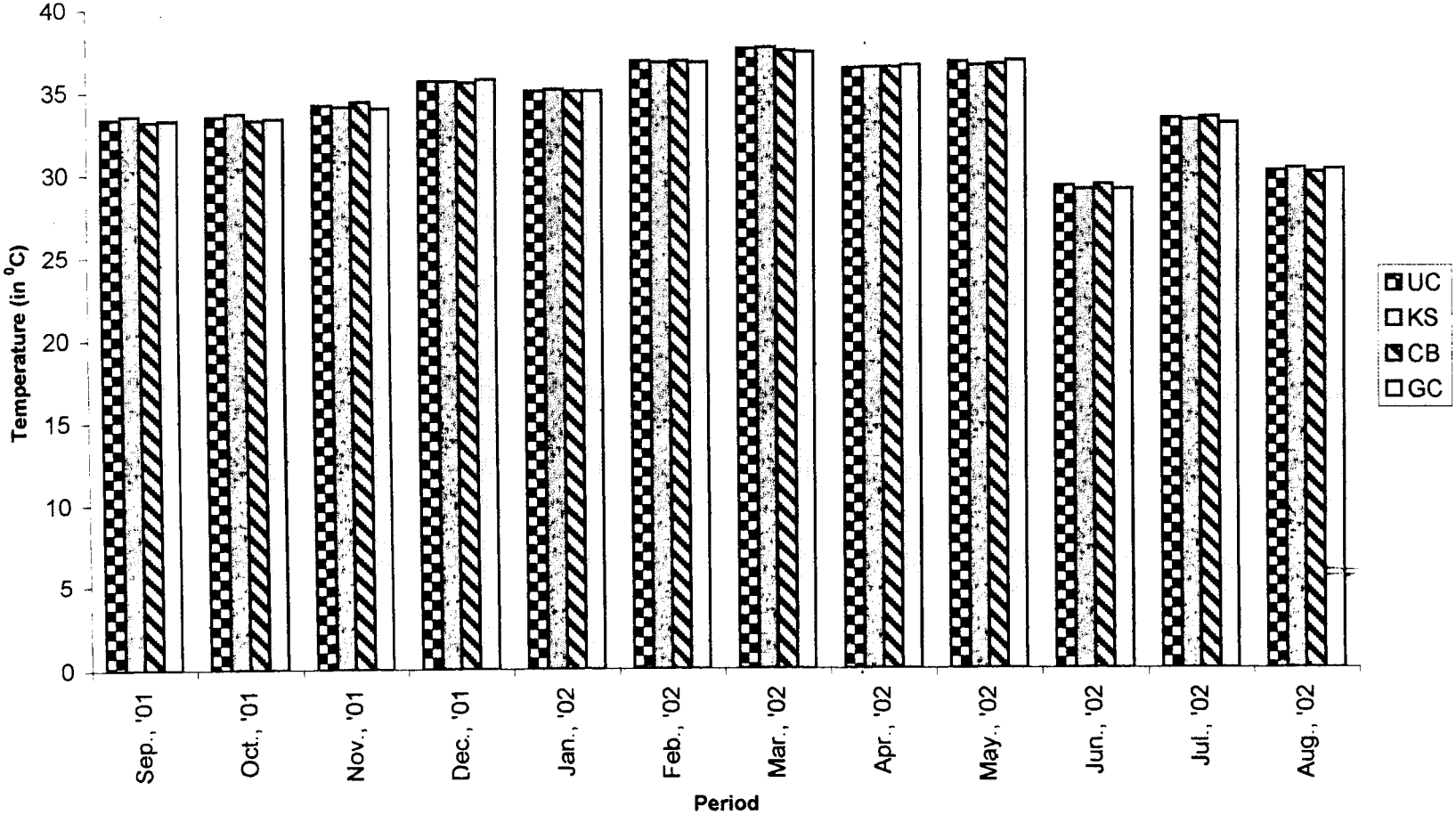


Plate 18 - Monthly temperature in the four study sites from Sept., 2001 to Aug., 2002



4. Description of New Species

(All measurements given in μm.)

Superfamily : Phthiracaroidea Grandjean, 1954.
Family : Phthiracaridae, Perty, 1841.
Genus : *Atropacarus* Ewing, 1917.

Generic diagnosis:

Fifteen pairs of notogastral setae. nine pairs of genital setae. Anoadanal plates each with five pairs of setae, three pairs of medial setae inserted near each other on inner margin of anoadanal plates. Two pairs of lateral setae.

***Atropacarus (Hoplophorella) chaliensis* sp.nov.**
(Plate-9, Fig. 4, Plate-19, Figs. 1-5, Plate-20, Figs. 1-6)

Colour	:	Wheat brown.	
Measurements	:	Aspis	Length: 230 (Range 208-236)
			Width : 110 (Range 102-116)
		Notogaster	Length: 447 (Range 409-457)
			Width : 322 (Range 312-348)

Aspis (Plate-19, Figs. 1 & 2)

Aspis elongated and flexed medio-ventrally. Two lateral carinae present as a pair of stumps on the aspis which stop abruptly at the middle of aspis. Seta *ro* (Plate-19, Fig. 4) short, blunt, smooth, curved inwards, measures 37 and inserted far below the anterior margin of the rostrum. Seta *le* (Plate-19, Fig. 5) long, stout, measures 110, barbed more than half of its length, barbs appear stronger at distal end and on the upper half. Seta *in* short reaching 13, thinner than *ro*, erect and inserted in between *le* and *bo*. All prodorsal setae with pronounced insertional

points and deeply inserted in the integument. Seta *ex* thinnest, measuring 29 and inserted near *bo*. Bothridium (Plate-19, Fig. 3) laterally opened. Sensillus (Plate-19, Fig. 3) long stalked with a length of 66 and gradually dilating to form a club shaped head. Lateral border of prodorsum with scattered foveolae. Postero-lateral margins of aspis with vertical striations of varying number which stop abruptly below the level of seta *le*. Posterior margin of the prodorsum below the level of *bo* wavy. Entire prodorsal integument punctated.

Notogaster (Plate-19, Fig. 1)

Notogaster highly convex with a round posterior border, the extreme posterior apex produced into a caud. 15 pairs of setae arranged on the notogaster as figured (Plate-19, Fig. 1). All setae resemble *le* in appearance (Plate-19, Fig. 6) and show variation in length ranging from 57-99, ps_3 the shortest h_2 the longest. Notogastral integument sculptured with round foveoles which follow a regular pattern of arrangement. Foveoles more distinct on the dorsal aspect, but feeble, sparsely arranged and often indistinct along the medio-lateral aspects. Micropunctations present on notogaster interspersed with foveoles. Sclerotisation well along the dorsal and lateral borders of notogaster.

Ventral Region

Labiogenal articulation stenarthric. Rutellum (Plate-20, Fig. 1) stout, broad with three notches, the central notch resembles a well developed blunt spine and the two lateral notches broad, the inner notch also produced into a pointed spine. Chelicerae (Plate-20, Fig. 2) broad

and stout with punctations on basal portion, each digit with four blunt teeth. A tubercle like structure called 'δ' present on the body of each chelicera. Seta *chb* smooth while *cha* with barbs at distal end. Pedipalp (Plate-20, Fig. 3) with a chaetotaxy of 0-2-3-8. Palpal tarsus with three eupathidia, *ul'*, *ul''* and *su*, one solenidion, 'ω', one barbed seta and three simple setae. Infracapitular setae smooth and show variation in length, *a* the longest. Gnathosomal integument punctated. Epimeral setal formula 1-0-1-1, seta on epimere 1 long, barbed and tapering. Setae on epimeres 3 and 4 almost equal and smooth (Plate-20, Fig. 4). Genital plates (Plate-20, Fig. 5) somewhat rectangular, carrying nine pairs of smooth setae, g_1, g_2 and g_3, minute and inserted in a transverse row. Distance between g_6, g_7, g_8 and g_9 almost equal. Anterior genital setae placed nearer compared to the posterior ones. A pair of small, smooth aggenital setae detected. Genital plates ornamented with foveoles. Anoadanal plates (Plate-20, Fig. 5) also rectangular with round posterior and concave anterior borders. Each plate bears three smooth, short setae at its inner posterior margin. Two pairs of adanal setae detected, ad_1 long, smooth and inserted at a level between an_2 and an_3. Seta ad_2 inserted far anteriorly on the adanal plate. Seta ad_2 short and barbed distally. Ventral plate lying adjacent to the anoadanal plate also foveolated.

Legs

All legs monodactylous with the claws bearing two spines each, distal spine longer and stouter than proximal spine. Chaetotaxy of leg I (Plate-20, Fig. 6) 1-4-3-4-18. Seta *v* on trochanter I, smooth and thin. Two solenidia σ_1 and σ_2 present on genu I, the former thicker and longer than

the latter, reaching four times of its length. Tibia I carries a single solendion φ, and three barbed setae *l'*, *l''* and *v*. Tarsus I carries three solenidia w_1, w_2 and w_3, w_1 stouter than the other two and with blunt tip. Famulus ε elongated, stump like and situated very near to w_1. Seta *tc'*, *tc''*, *p' u'* and *u''* with curved tips. Setae *s*, *pv''*, *p'* and *p''* eupathidic, setae *v'*, *u'* and *u''* provided with a few barbs.

Material Examined

Holotype: ♀ Paratypes: 20♂♂ and 30 ♀♀ collected from the beach soils at Chaliyam, Kerala, India on 20-05-2001.

Remarks

A close scrutiny of the morphological features of the new species *A. chaliensis* with other known species of the genus helped to detect its similarity with *A. venusta* described by Niedbala (1983a) from Uganda in the nature of prodorsal and notgastral setae and in the number and arrangement of epimeral, genital and ano-adanal setae. But on the basis of the following characters, the present species has been assigned a new taxonomic status.

1. Absence of dorsal carina on aspis.
2. Barbed nature of setae ad_2.
3. Elongated nature of anal seta an_1 -an_3.
4. Possession of palp setal formula of 0-2-3-8 and leg chaetotaxy of 1-4-3-4-18.

Atropacarus (Hoplophorella) crenulus **sp. nov.**
(Plate-9, Fig. 5, Plate-21, Figs. 1-10)

Colour : Creamy white

Measurements: Aspis Length: 208 (Range 202-214)
Width : 100 (Range 96-105)
Notogaster Length :440 (Range 436-444)
Width : 300 (Range 294-306)

Aspis (Plate-21, Figs. 1 & 2)

Aspis oval in shape with slightly pointed tip. Seta *ro* stiff, with slight bent, smooth and inserted slightly away from the rostral apex, measuring 60 in length., Seta *le* largest among all the prodorsal setae, measuring 90 bearing fine barbs on one side and backwardly directed. Seta *in* small and smooth, measuring 22 and inserted very close to base of *bo*. Seta *ex* not visible. *ss* elongate with a round fan shaped projection towards the tip with crenulation along the anterior margin (Plate-21, Fig. 3). Bothridium cup shaped, directed posteriorly towards the lateral side. Prodorsum exhibits prominent foveolae towards the anterior one third of the tip with sparse and minute punctation towards the posterior region. A thin median ridge extends from the base of the aspis to a short distance while lateral carina with a prominent ridge projects towards the centre enclosing *bo* and *in*.

Notogaster (Plate-21, Fig. 1)

Notogaster globular with rounded posterior end. Ornamentation more pronounced than on aspis, especially along the mid dorsal region of notogaster and becoming less prominent laterally. 15 pairs of notogastral setae. Seta c_1 with fine barbs all along its length, all other

setae with fine barbs towards the tip alone. Setae e_1, e_2, h_1, h_3, ps_1, ps_2 and ps_3 measure 42-50 while others measure 82-92.

Ventral Region

Rutellum (Plate-21, Fig. 4) broad and thick with three well developed bent notches of equal size. Chelicerae stout with well developed teeth on both digits. Setae *cha* and *chb* smooth and pointed. (Plate-21, Fig. 5). Pedipalp with a chaetotaxy of 0-0-2-3-8, palpal solenidion thick and blunt (Plate-21, Fig. 6). Infracapitulum (Plate-21, Fig. 7) with three setae *a, h* and *m,* all simple, smooth with pointed tip. Epimeral setal formula 1-0-1-1. All setae smooth and pointed, but seta of epimere 1 longer than the others (Plate-21, Fig. 8). Each genital plate (Plate-21, Fig. 9) rectangular in shape, carrying the broad and short aggenital plate which in turn carries a minute seta *ag* at its outer corner. Genital setae g_1 -g_9 clearly visible, arranged in a row towards the inner margin, g_1-g_3 much smaller than the others and very closely arranged. Genital plates ornamented with foveoles. Ano-adanal plates broader towards the middle region and with rounded posterior border. Three pairs of anal and two pairs of adanal setae present. Anal setae simple, thin and with pointed tip. ad_1 much longer than ad_2 with a 90^0 bent towards the base, and with straight pointed tip. ad_2 resembles anal setae. Integument of anoadanal plate with a few wrinkles towards the lateral and basal portion.

Legs

All legs monodactylous, with a stout claw on each tarsal segment. Chaetotaxy of leg I (Plate-21, Fig. 10) 1-4-3-5-15. Seta of trochanter I with

a few barbs. Femur I with four setae, v' and v'' with barbs, d and l' smooth. Genu I carries two solenidia σ_1 and σ_2. σ_1 very long, thick and pointed towards the tip. σ_2 short and pointed. Tibia I bears five setae, of which φ long and blunt solenidion, v' barbed, others smooth. Tarsus I bears 15 setae including three solenidia w_1, w_2 and w_3, w_1 and w_3 more or less similar, w_2 longer. Famulus ε seen close to w_2. Seta s absent. Claw on the tarsus blunt with a basal ventral tooth.

Material Examined

Holotype: ♀, paratypes: seven ♀♀ and two ♂♂ collected from Chaliyam beech soil on 4-6-2001.

Remarks

On comparing the morphological characters of the present specimen with other described species, it shows close similarity with *A. (H.) chaliensis* sp. nov. in the following characters.

1. Notogastral setae with barbs towards distal half.
2. Long and thin nature of anal setae and ad_1.
3. Arrangement of genital setae.

But the present specimen can be distinguished from *A. (H.) chaliensis* in the following features .

1) Sensillus with broad tip.
2) Seta *le* with fine barbs on one side
3) Absence of seta *ex*.
4) Seta ad_2 thin and smooth with pointed tip like anal setae.

5) Difference in leg chaetotaxy; chaetotaxy of leg 1 in *A. (H.) chaliensis* 1-4-3-4-18 while that of the present species 1-4-3-5-15

These features justify the erection of a new taxon for the present specimen.

***Atropacarus (Hoplophorella) reticulatus* sp. nov.**
(Plate-22, Figs. 1-10)

Colour : Creamy white.

Measurements : Aspis Length: 208 (Range 192-208)
Width : 96 (Range 88-96)
Notogaster Length: 380 (Range 368-380)
Width: 240 (Range 232-240)

Aspis (Figs. 1 & 2)

Aspis elongated with well developed lateral carina which bulges outwards towards the middle of the aspis. Rostral apex conical. Seta *ro* thick and foliate towards the tip, inserted away from rostral apex and measuring 36. Seta *le* longest of all prodorsal setae with uniform thickness, measuring 53. Seta *in* thin and pointed, 16 long. Seta *ex* not visible. Bothridium cup shaped with a wide opening. Sensillus (Fig. 4) with long thin pedicel becoming broader towards the tip, crenulated and spinous along the posterior margin. Prodorsal integument provided with a number of longitudinal striations which cross one over the other presenting a highly reticulated appearance; these striations not reach the rostral apex, so that the rostral tip remains smooth.

Notogaster

Notogaster convex with its extreme posterior end produced into a caud. 15 pairs of smooth spoon shaped setae (Fig. 3) ranging in size from 40-60. Seta c_1 the longest and ps_3 the shortest. Integument of notogaster with fine punctations.

Ventral Region

Rutellum (Fig. 5) broad and thick with three well-developed notches, the median one triangular while the lateral ones rounded. Chelicerae (Fig. 7) with four teeth on the fixed digit and three on the movable digit. Setae *cha* and *chb* smooth and pointed. Pedipalp (Fig. 9) with a chaetotaxy of 2-2-8. Epimeral setal formula 1-0-1-1 (Fig. 6), seta of first epimere double the size of the others. All setae thin and pointed. Genital plate rectangular, carrying a broad aggenital plate anteriorly, which bears a minute agential seta *ag* at its outer corner. Genital setae g_1-g_5 minute and very closely arranged along the anterior inner margin while g_6-g_9 bigger and arranged at equal distance along the inner margin of the genital plate (Fig. 8). Anoadanal plate broader at the anterior region, almost conical towards the posterior region, carrying three pairs of anal and two pairs of adanal setae. Seta ad_1, long and foliate while ad_2 spiniform. Anal setae closely arranged, thin and long with pointed tip. Integument of anoadanal plate finely punctated.

Legs

All legs monodactylous with a thick claw. Chaetotaxy of legs reduced. Chaetotaxy of leg I (Fig. 10) 1:3:3:4:15. Trochanter I with a long

thin, smooth seta. Femur I carries three setae, seta *d* thin and long, *v'* slightly barbed. Genu carries two solenidia, a long σ_1 and a short σ_2. Tibia bears four setae including solenidion φ. Tarsus bears fifteen setae including three solenidia ω_1, ω_2, and ω_3, ε seen closely associated with w_1. Seta *s* absent. Claw thick and stout with a spinous projection at the base ventrally.

Material Examined

Holotype: ♀, paratypes: three ♀♀ and two ♂♂ collected from secondary forest area of Calicut University Campus on 14-6-2001.

Remarks

A detailed examination of the morphological features of the present species with the known species of the genus *Atropacrus* helped to detect its similarity with *A. glaucus* described by Hammer (1972) in

1) The spoon shaped notogastral setae
2) The disposition of genital setae g_6-g_9
3) Long pointed nature of anal setae
4) Foliate nature of ad_1 and
5) Reduced chaetotaxy of legs

But on the basis of the following specific characters, it differs from *A. glaucus* and hence been assigned to a new taxonomic status.

1) Thick nature of seta *ro*.
2) Elongated nature of seta *le*
3) Absence of spines on notogastral setae
4) Presence of longitudinal striations on prodorsum which cross one over the other.

Atropacarus (Hoplophorella) keralensis. sp. nov.
(Plate-9, Fig. 6, Plate-23, Figs. 1-12)

Colour	:	Yellowish brown	
Measurements	:	Aspis	Length: 232 (Range 218-242)
			Width : 108 (Range 104-116)
		Notogaster	Length: 384 (Range 368-396)
			Width : 300 (Range 292-312)

Aspis (Plate-23, Figs. 1 & 2)

Aspis oblong with rounded rostral apex and without lateral carina. Seta *ro* thick with a definite inward bent and a few fine barbs, measuring 22 in length, inserted away from rostral apex. Seta *le* the largest among the prodorsal setae, measuring 44, lanceolate and smooth. Seta *in* small, smooth and spine like measuring 11 and inserted in between *le* and *bo*. Seta *ex* minute and placed posterior to *bo*. Sensillus elongate, proximal two third very narrow while the distal one third highly expanded with a crenulated anterior margin (Plate-23, Fig. 3). Bothridium cup shaped with a wide anteriorly directed opening through which emerges the *ss*. On each side of the prodorsum lateral carina present. Prodorsum exhibits wrinkled ornamentation along the lateral side, feeble punctations medially and varying number of vertical striations posteriorly (Plate-23, Fig. 2).

Notogaster (Plate-23, Fig. 1)

Notogaster densely foveolate, more towards the mid-dorsal region. 15 pairs of notogastral setae, setae c_1, d_1 and e_1 (Plate-23, Fig. 4) of uniform width with inward bent while the rest spoon shaped with short

basal portion and with medial thickening (Plate-23, Fig. 5). Seta d_1 longest (44), ps_1 shortest (22), others more or less of same length.

Ventral Region

Rutellum (Plate-23, Fig. 6) broad and stout with three well developed notches, central notch smaller than the other two. Chelicerae (Plate-23, Fig. 7) stout and punctate, setae *cha* and *chb* smooth and of almost equal length. Pedipalp (Plate-23, Fig. 6) five segmented with a chaetotaxy of 0-0-2-2-9. Infracapitulum (Plate-23, Fig. 6) bears three setae, *a*, *h*, and *m*, all setae smooth and almost of the same length. Gnathosomal integument with fine punctations. Epimeral setal formula 1-0-1-1 (Plate-23, Fig. 8). Setae of epimere 1 foliate and longer while those of 3 and 4 thin and pointed towards tip. Genital plate (Plate-23, Fig. 9) rectangular in outline carrying the broad aggenital plate anteriorly. A minute aggenital seta, *ag* seen at the outer corner of each aggenital plate. Genital setae g_1-g_3 closely arranged, g_4-g_9 visible clearly, arranged in a row towards the inner margin. All setae small and smooth. Genital plates ornamented with interrupted lines and fine punctations. Anoadanal plate (Plate-23, Fig. 9) rectangular like the genital plate and almost of the same length. Three pairs of anal and two pairs of adanal setae present. Anal setae of equal length, smooth with pointed tip (Plate-23, Fig. 10). ad_1 long and foliate (Plate-23, Fig. 11), ad_2 smaller, smooth with pointed tip like anal setae. Integument of anoadanal plate provided with wrinkles along the lateral and posterior periphery.

Legs

All legs monodactylous with a thick empodial claw on each tarsal segment. Chaetotaxy of leg I (Plate-23, Fig. 12) 1-4-3-6-16. Seta of trochanter I thin and smooth with fine tip. Femur I with four setae with varying degrees of barbation. Genu I carries two solenidia σ_1 and σ_2, the latter twice longer than the former. Tibia I carries a single solenidion φ. Seta *d* very small and seen in close association with the solenidion. Setae *l'* and *l''* smooth, *v'* and *v''*with fine barbs. Tarsus I with 16 setae. Of the three solenidia, w_2 and w_3 of equal length, w_1 smaller. Famulus (ε), smooth and pointed. Claw on tarsus 1 stout with rounded apex bearing two spinous teeth ventrally towards the base.

Material Examined

Holotype: ♀, paratypes: 17 ♀♀ and nine ♂♂ collected from soil and litter samples of Botanical Garden of Calicut University, on 03-08-2001.

Remarks

A comparison of the present species with other described species of the genus *Atropacarus* reveals its resemblance to *A. rangiroaensis* (Hammer, 1972) in the following features.

1. In the absence of lateral carina.
2. Spoon shaped setae of notogaster.
3. Slender nature of ad_2
4. Long and comparatively thick nature of anal setae.

But the present species can be easily distinguished from *A. rangiroaensis* by the following characters.

1. Foveolate nature of integument.
2. Barbed nature of seta *ro*
3. Foliate nature of setae c_1, d_1 and e_1, with uniform thickness.
4. Arrangement of genital setae.

The above characters enable to assign the present species to a new taxon.

Superfamily : Phthiracaroidea Grandjean, 1954
Family : Phthircaridae Perty, 1841.
Genus : *Phthiracarus* Perty, 1839.

Generic Diagnosis

Setae an_1 and an_2 located near the paraxial margin of the ano-adanal plate. Genital setae situated along two rows, seta g_6 above seta g_5. Setae of notogaster smooth and thin, tapering to a point at the end.

***Phthiracarus haqi* sp.nov.**
(Plate-10, Fig. 1, Plate-24, Figs. 1-5, Plate-25, Figs. 1-4)

Colour : Golden yellow.
Measurements : Aspis Length : 180 (Range 176-180)
Width : 96 (Range 93-102)
Notogaster Length : 360 (Range 358-365)
Width : 240 (Range 238-244)

Aspis (Plate-24, Figs. 1&2)

Aspis oval in shape with blunt rostral apex and a long lateral carina, *ro* thin and smooth, measuring 24, inserted a little below the rostral apex. Seta *le* largest among the prodorsal setae, thin with pointed tip measuring 72. Seta *in* small and smooth. Seta *ex* as long as *ro*. All prodorsal setae thin and fine. Sensillus (*ss*) (Plate-24, Fig. 3) clavate, having a rounded oval head and thin long peduncle, sigmoid in proximal portion. Bothridium cup shaped with a wide, laterally directed opening. Prodorsum exhibits longitudinal bands extending from base to the tip and a transverse band running across the middle of aspis.

Notogaster (Plate-24, Fig. 1)

Notogaster oval in shape with rounded posterior end and bears 15 pairs of notogastral setae. All setae thin and tapering to a point at the tip. Seta c_1 longest, measuring 82, ps_2, ps_3 and h_3 small measuring 42 each. Other setae range between 54-78 in length. Integument with fine punctations.

Ventral Region

Rutellum (Plate-24, Fig. 4) thick and stout with three notches, middle one triangular in shape and smaller in size while lateral notches rounded and larger. Chelicerae (Plate-24, Fig. 5) thick and stout with well developed teeth on both digits. Setae *cha* and *chb* thin and pointed, *chb* double the size of *cha*. Pedipalp (Plate-25, Fig. 1) with a chaetotaxy of 0-0-2-3-8. Palpal solenidion thick with blunt tip. Infracapitulum bears three setae, *a*, *h* and *m*, all setae thin, smooth and with pointed tip.

Epimeral setal formula 1-0-1-1 (Plate-25, Fig. 2). All setae smooth and pointed. Seta of epimere 1 longer than the others. Each genital plate (Plate-25, Fig. 3) rectangular in out line, carrying the short and broad aggenital plate anteriorly with a minute aggenital seta *ag* located at its outer corner. Genital setae arranged in two rows. Setae g_1-g_5 small and more closely arranged towards the inner margin of the genital plate. The posterior four setae comparatively long and arranged with wider interspace, g_6 inserted above the insertion point of seta g_5, but outwardly. Anal plate with a strong anterior lock. Two anal setae situated close together on the median margin of the plate. Adanal seta ad_1 slightly smaller than ad_2 and ad_3. Insertion of ad_1 far above while ad_2 and ad_3 inserted close together towards the posterior end.

Legs

All legs monodactylous with a stout claw borne on each tarsal segment. Chaetotaxy of leg I (Plate-25, Fig. 4) 1-4-5-5-19. Seta of trochanter I long, thin and with tapering end. Femur I bears four setae, setae *d*, *l'* and *v'* smooth, *v"* slightly barbed. Genu I bears five setae including two solenidia σ_1 and σ_2, the former being much larger. Tibia I caries five setae including the solenidion, φ. Seta *v'* slightly barbed, others smooth. Tarsus I bears 19 setae including three solenidia ω_1 , ω_2 and ω_3 . Seta ε closely associated with ω_1. Claw on tarsus I blunt and bears two ventral teeth basally.

Material Examined

Holotype: ♀, paratypes: four ♀♀ and two ♂♂ collected from soil and litter samples of Kakkanchery on 17.08.2001.

Remarks

A comparison of the morphological characters of the present species revealed its resemblance to *P. crispus* Hammer, 1972 in a few features as follows.

1) In the presence of a long lateral carina on the prodorsum.
2) Nature and disposition of notogastral setae

But it exhibited marked differences from the above species and other known species of the genus which are listed as,

1) Sensillus long and thin at the base, becoming expanded forming a club shaped tip.
2) ad_1, ad_2 and ad_3 longer than anal setae, ad_2 longest.
3) Chaetotaxy of leg I, 1-4-5-5-19.

Considering these features, the present species is given a new taxonomic status.

Superfamily : Lohmannoidea Grandjean, 1967
Family : Lohmanniidae Berlese, 1916
Genus : *Annectacarus* Grandjean, 1950

Generic Diagnosis

Genital plates without transverse suture. Preanal plate narrow. Anal and adanal plates fused. Two pairs of anal setae. Four pairs of adanal setae. Pygidial neotrichy present.

Annectacarus malabaricus sp. nov.
(Plate-10, Fig. 2, Plate-26, Figs. 1-2, Plate-27, Figs. 1-6)

Colour : Pale yellow to dark brown
Measurements : Length : 488 (Range 485-504)
Width : 252 (Range 248-266)

Dorsal Region (Plate-26, Fig. 1)

Body conical anteriorly with somewhat straight lateral borders. Posterior region rounded. Micro sculpture of integument consists of irregular polygons, superimposed on finely punctate integument.

Prodorsum

Prodorsum almost one and a half times broader than long. Rostrum entire and conical with rounded borders. Prodorsal setae long and bilaterally barbed. Seta *ro* inserted slightly below the rostral tip, 48 in length and bent externally. Setae *le* and *exa* almost straight and measure 72. Seta *exp* resembles *exa* but slightly longer with a measurement of 78. Seta *in* placed far below, very close to *bo* and as long as seta *exp*. Bothridium bell-shaped, opens laterally. Sensillus pectinate with 14 branches (Plate-27, Fig. 1). Two area porosae located between pseudostigmata. Prodorsal integument richly ornamented in an irregular pattern of polygonal reticulum.

Notogaster

Notogaster straight sided anteriorly and oval posteriorly. Dorsosejugal suture clearly visible. Notogastral bands s_1 and s_2 developed, but discontinuous medially. Characteristic heterotrichy

could be observed on notogaster. Eighteen pairs of notogastral setae present as shown in figure 1. Setae c_1, d_1 and e_1 simple, small and smooth with a measurement of 13-16 in length. These setae placed one below the other. Seta d_1 placed farther away from the mid-dorsal line. Setae c_2 and the pygidial neotrichial setae *n* and *r* finely barbed and range in length between 45-50. Setae d_2, f_1, h_1, h_2 and h_3 range between 60-70 in length and similarly barbed. Setae d_3, e_2, f_2, ps_2 and ps_3 barbed and much longer, measuring between 70 and 80. Setae c_3 and ps_1 show maximum length of 80-90 and barbed like other notogastral setae. Notogastral fissure *im* alone clearly visible in dorsal view, located near the insertion of seta e_2 on each side. Ornamentation of notogaster closely resembles that of prodorsum.

Ventral Region (Plate-26, Fig 2)

Rutellum (Plate-27, Fig. 2) stout and well developed, ending in four notches at its tip, partially overlapped by the chelicera. Chelicerae (Plate-27, Fig. 3) broad and stout with well developed digits. Digitus fixus bears three teeth while digitus mobilis carries only two. Cheliceral setae smooth and simple, *chb* longer than *cha*. Pedipalp (Plate-27, Fig. 4) with a chaetotaxy of 0-1-0-1-9. Palpal tarsus bears two distal eupathidia (*cm, acm*) and a single solenidion (*w*) . Infracapitulum with four pairs of setae, *a, h,* m_1 and m_2, of which *a* smooth, *h,* m_1 and m_2 barbed (Plate-27, Fig. 5). Sejugal apodemata well developed. Each epimere possesses clear cut boundaries. Posterior border of epimere 1 discontinuous medially with bifurcated edge towards the centre. Epimere 2 with complete posterior boundary while epimeres 3 and 4 incomplete medially. Legs III

and IVoriginate from the postero-lateral corner of epimers 3and 4. Epimeral setal formula 6-3-3-4. Setae *1a, 1e, 2a, 3a* and *4a* small, thin and without barbs. Others strongly barbed. Seta 1*f* much longer than the others. Aggenital plates triangular. Genital plates elongated, without transverse sutures, each with 10 setae arranged in two rows, an antiaxial row of four and paraxial row of six. Paraxial setae small and simple. First, third and fourth antiaxial setae simple, while second bigger and barbed. Preanal plate thin and rectangular in shape with a central downward depression. Anoadanal plates fused and elongated with a pointed posterior apex. Anoadanal setal formula typical of the genus i.e. 2:4. Both anal and adanal setae barbed. Seta an_1 placed between ad_3 and ad_4 and an_2 between ad_2 and ad_1. Fissure *ia* semilunar shaped, *ip* and *ih* visible as narrow slits. Entire ventral region including the infracapitulum and epimeral region exhibits the same pattern of ornamentation as that of the dorsal side.

Legs

All legs monodactylous with a stout empodial claw. Chaetotaxy of leg I (Plate-27, Fig. 6) 0-5-5-5-16. Trochanter I small, conical and without any setae. Femur I stout with an anterolateral keel and a prominent dorsal basal notch. It bears five setae, *bv* and *v* stout, bent and barbed unilaterally, *d* simple and smaller but *l'* and *l"* barbed on both sides. Genu I short but broad, carrying five setae including two solenidia σ' and σ'', seta *d* long, thin, tapering and closely associated with σ', *l'* barbed bilaterally. Tibia I carries five setae, solenidion φ long and whip like, *l* simple, *v*, xt_1 and xt_2 barbed bilaterally. Tarsus I with 16

setae including two solenidia w_1 and w_2, the former stout with thin, pointed tip. Setae *s* and *m* eupathidic. All leg segments show ornamentation of reticulated punctations.

Material Examined

Holotype: ♀, paratypes: four ♀♀ and two ♂♂ collected from Acacia plantations, University of Calicut, Kerala, India on 4-7-2000.

Remarks

The genus *Annectacarus* was erected by Grandjean (1950) with *A. mucronatus* as type species. The present species, *A. malabaricus* on comparison with the previously known 11 species, is found to exhibit close resemblances to *A. aokii* described by Jaikumar *et al.* (1994) in the number of notogastral setae, nature of setae c_1, d_1 and e_1, pedipalp and rutellum. However, *A. malabaricus* possesses certain characteristic deviations from *A. aokii* based on which it has been raised to the status of a new species. The present species can be distinguished by the following characters:

1. Notogastral bands s_1 and s_2 developed and incomplete medially.
2. Sensillus with 14 branches.
3. 18 pairs of notogastral setae.
4. Epimeral setal formula 6-3-3-4.
5. Chaetotaxy of leg I: 0-5-5-5-16.

Annectacarus plumosus sp. nov.

(Plate-10, Fig. 3, Plate-28, Figs. 1-2, Plate-29, Figs. 1-5)

Colour: : Brownish yellow

Measurements : Length : 645 (Range 632-650)
Width : 330 (Range 320-332)

Dorsal Region (Plate-28, Fig 1.)

Body large with conical anterior and oval posterior ends.

Prodorsum

Prodorsum broader than long, conical in shape. Rostral apex rounded. Seta *ro* finely barbed, inserted a little below the rostral apex and measures 60. Seta *le* inserted well below the level of *ro*, smooth and 96 long. Setae *exa* and *exp* inserted along the lateral border of lamella and of the same size, 75 long and smooth. Seta *in* smooth, inserted inner to and slightly below the level of *bo* and measures 82. Bothridium large with lateral opening. Sensillus pectinate with 18-20 branches on one side (Plate-29, Fig. 1). The entire surface of prodorsum ornamented with fine granular punctations and a few scattered rounded area porosae.

Notogaster

Notogaster elongated with rounded posterior and straight lateral margins. Posterior notogastral region exhibits slight neotrichy. In addition to the normal 16 pairs of notogastral setae, three pairs of neotrichial setae present. All notogastral setae smooth. Setae c_1, d_1 and e_1 small with pointed tip, ranging in size between 25-30. f_1 and h_1 slightly foliate and measures 50 and 62 respectively. Marginal setae longer and range in size between 45-90. Neotrichial setae small, curved with

pointed end, measure 25-30. Fissure *im* visible below the insertion point of seta d_2. Notogastral bands absent. Ornamentation of notogaster similar to that of prodorsum.

Ventral Region (Plate-28, Fig. 2)

Rutellum (Plate-29, Fig. 2) with three prominent blunt protruberances at tip. Chelicerae (Plate-29, Fig. 3) strong and well built with three and two teeth on the movable and immovable digits respectively. Pedipalp five segmented with a chaetotaxy of 0-1-0-1-8 (Plate-29, Fig. 4). Infracapitulum with four pairs of setae, *a*, *h*, m_1 and m_2. Seta *h* plumose, others smooth and simple. Epimeral boundaries well marked, second epimeral region with a transverse band in the middle. Epimeral setal formula 5-4-4-3. Setae *1a*, *2a*, *3a* and *4a* very small, smooth and simple, others with barbs. A pair of triangular aggenital plate seen in the antero-lateral corner of genital plate. Genital plates undivided with six pairs of paraxial and four pairs of antiaxial setae. Second pair of antiaxial setae with barbs, all other genital setae smooth. Preanal plate narrow but broad with a median downward excrescence. Anal and adanal plates fused. Four pairs of adanal and two pairs of anal setae present. All setae smooth. Anal setae smaller than adanal setae. Lyrifissures *ia* and *ih* visible. Integument of ventral region with fine granular punctations.

Legs

All legs monodactylous. Leg I (Plate-29, Fig. 5) with a chaetotaxy of 0-4-4-4-6. Leg segments ornamented with fine punctations. Setae *d* and *v* on femur I foliate. Setae *l'* and *l''* ciliate. Femur I with a dorsal

ridge. Genu I with a single solenidion σ'. Setae *d* and *l''* simple. *l'* with prominent barbs. Tibia I possesses a very long solenidion φ, seta l' barbed unilaterally, xt_1 and xt_2 simple. Tarsus I with two solenidia. ω_1 and ω_2 and famulus *ε*. Seta *pv* with small barbs. Others smooth.

Material Examined

Holotype: ♀, paratypes: four ♀♀ and one ♂ collected from litter and soil samples from the Government Arts & Science College, Calicut on 2-4-2001.

Remarks

Comparative studies on the members of the genus *Annectacarus* reveal that the present species show superficial resemblance to *A. malabaricus* sp.nov. in the number of infracapitular setae, nature of genital setae and chaetotaxy of tibia I. Closer scrutiny shows that it strongly differs from the former in the number of notogastral setae, smooth nature of notogastral setae, infracapitular setae m_1 and m_2 and adanal and anal setae, epimeral setal formula and the absence of notogastral bands. The present species can be distinguished from all other described species of *Annectacarus* by the following features.

1. Absence of notogastral bands.
2. Seta *ro* finely barbed, other prodorsal setae smooth.
3. Sensillus with 18-20 branches.
4. 19 pairs of smooth notogastral setae.
5. Epimeral setal formula 5-4-4-3.
6. Chaetotaxy of leg I: 0-4-4-4-16.

Superfamily: Lohmannoidea Grandjean, 1967
Family : Lohmanniidae Berlese, 1916
Genus : *Haplacarus* Wallwork, 1962

Generic Diagnosis

Genital plates without transverse suture. Preanal plate broad. Anal and adanal plates fused. One pair of anal and four pairs of adanal setae present. Notogastral and epimeral region without neotrichy.

***Haplacarus xavieri* sp.nov.**
(Plates -30, Figs. 1-2, Plate-31, Figs. 1-5)

Colour : Pale yellow to light brown
Measurements : Length : 552 (Range 545-564)
Width : 288 (Range 280-294)

Dorsal Region (Plate-30, Fig. 1)

Body elongated with conical anterior and posterior ends. Microsulpture of the integument in the form of uniformly distributed papillae and fine punctations.

Prodorsum

Anterior margin of the rostrum smooth and entire without incision. All prodorsal setae foliate and weakly serrated. Seta *ro* inserted well behind the anterior tip of rostrum, directed forward and measures 74. Seta *le* inserted below the level of *ro* and 72 long. Seta *exa* curved at the base and measures 92. Seta *exp* directed posteriorly and measures 72. Seta *in* inserted very close to *bo* and measures 96. *ss* pectinte with 14-15

long branches (Plate-31, Fig. 1). A prodorsal band fomed of 10-12 papillae extends between the interlamellar setae. The integument of prodorsum exhibits uniformly distributed papillae which become smaller in size towards the tip of rostrum.

Notogaster

Notogaster elongate with straight margins. Nine notogastral bands detected of which s_2, s_3, s_6, s_8 and s_9 incomplete towards the centre. 16 pairs of notogastral setae. All the setae foliate and weakly serrate. Microsculpture of notogaster consists of small knob-like papillae distributed uniformly except along the notogastral bands

Ventral Region (Plate-30, Fig. 2)

Rutellum (Plate-31, Fig. 2) well developed with 2-3 prominent knobs towards the tip. Chelicerae (Plate-31, Fig. 3) sclerotised moderately, digitus mobilis with two and digitus fixus with three teeth. Setae *cha* and *chb* smooth. Pedipalp (Plate-31, Fig. 4) with a chaetotaxy of 0-0-1-0-9. Infracapitulum with four pairs of setae. Setae *a* and m_1 smooth and simple, while *h* and m_2 barbed. Antero-lateral margin of genital plate bordered by triangular aggenital plate. Genital plate with out transverse suture. Ten setae on each genital plate, four antiaxial and six paraxial in position. Paraxial setae thin, small and smooth, antiaxial setae long, slightly barbed. Preanal plate broad with central downward projection posteriorly. Anal and adanal plates fused, each carrying one anal and four adanal setae. Anal seta much smaller than adanal setae and finely barbed. Adanal setae foliate and barbed. Fissure *ia*, *ip* and *ih*

clearly visible. A few area porosae distributed on either side of the ventral plate. Ornamentation of ventral region consists of irregularly distributed papillae, smaller than that on the dorsal side.

Legs

All legs monodactylous, chaetotaxy of leg I (Plate-31, Fig. 5) 0-5-5-4-17. Seta *v* on femur I highly foliate with midirib and serrate. Setae *bv* and *d* smooth. Setae *l'* and l" foliate and serrate. Genu I carries a slenidion *σ*. Seta *v* like that of femur I. Setae *l'*, *l"* and *d* simple and smooth. Tibia I carries a long solenidion *φ*. Setae *l'*, *l"* long, *l'* barbed, *xt* highly foliate and serrate. Tarsus I with two solenidia w_1 and w_2. Setae *pv'* and *pv"* small, well foliate and serrate. Seta *m* long, foliate and serrate. Seta *s* long and smooth. Other setae smooth with varying length.

Material Examined

Holotype: ♀, paratypes: 11 ♀♀ and six ♂♂ collected from litter and soil samples from Botanical garden of Calicut University on 24-08-2001.

Remarks

The genus *Haplacarus* was erected by Wallwork in 1962 with *H. foliatus* as type species. The genus at present includes 10 species described from different parts of the world. The new species *H. xavieri* on comparison with the previously known species of *Haplacarus* shows similarity to *H. porosus* described by Haq and Clement (1995). The common morphological features detected are the nature of sensillus,

number of notogastral and anal setae. However the present new species differs from *H. porosus* in the incomplete nature of notogastral bands s_2, s_3, s_6, s_8, and s_9 and in the nature of infracapitular and adanal setae and in the possession of a prodorsal band. The unique features of *H. xavieri* are.

1. Presence of nine notogastral bands, s_2, s_3, s_6, s_8, and s_9 incomplete.
2. Sensillus with 14-15 branches.
3. Infracapitular setae *a* and m_1 smooth, *h* and m_2 barbed.
4. A prodorsal band formed of 10-12 papillae extends between the interlamellar setae.

***Haplacarus davisi* sp. nov.**

(Plate-32, Figs. 1-2, Plate-33, Figs. 1-5)

Colour : Golden brown
Measurements : Length : 553 (Range 540-558)
Width : 320 (Range 310-322)

Dorsal Region (Plate-32, Fig 1)

Body fairly elongated and flat with conical anterior and rounded posterior ends. Integument with rounded foveolae.

Prodorsum

Prodorsum triangular with broad base and conical anterior region. A small conical projection present in the middle of the lateral prodorsal margin. Five pairs of prodorsal setae, smooth and setiform. Seta *ro* inserted far below the tip of rostrum and measures 54. Seta *le*

measures 90, inserted well below and outer to the level of *ro*. Seta *in* originates just below and inner to the level of *bo* and of same length as *le*. *exa* measures 85 and *exp* 68. *ss* pectinate with 13-14 branches (Plate-33, Fig. 1). A prodorsal band formed of 6-8 crescentic area porosae present between the insertional points of setae *in*. Prodorsal integument ornamented with rounded foveolae which become smaller in size towards the rostral apex.

Notogaster

Notogaster elongated, lateral sides straight and rounded posteriorly. Dorsosejugal suture distinct. Eight notogastral bands formed of closely arranged circular area porosae present. S_3 and s_4 fused towards the mid line. Sixteen pairs of notogastral setae. All setae smooth and setiform. Marginal setae longer, range in size 75-82. Central setae smaller and measure 55-66. Notogaster ornamented with rounded foveolae towards lateral and posterior side.

Ventral Region (Plate-32, Fig. 2)

Rutellum (Plate-33, Fig. 2) with three prominent blunt teeth. Chelicerae (Plate-33, Fig. 3) stout and well sclerotised. Setae *cha* and *chb* smooth. Pedipalp (Plate-33, Fig. 4) five segmented with a chaetotaxy of 0-1-1-0-9. Infracapitulum with four pairs of smooth setae. Epimeral setal formula 3-1-3-3. All setae smooth. Anterolateral margin of genital plate bordered by triangular aggenital plate. Genital plates without transverse suture and bear four antiaxial and six paraxial setae. Paraxial setae smaller. All setae smooth. Preanal plate broad with a median downward

excrescence. Anal and adanal plates fused. Anoadanal setal formula typical of the genus i.e., 1:4. All setae smooth. Fissure *ia* located outside sejugal apodeme, *ip* near the postero-lateral margin of the body. Integument of the ventral region with fine punctations.

Legs

All legs monodactylous. Chaetotaxy of leg I (Plate-33, Fig. 5) 0-5-5-4-18. Seta *d* on femur I foliate and barbed. Seta *l''* stouter and barbed. Setae *bv*, *v'* and *l'* smooth. Genu I bears five setae including solenidion σ. Seta *l'* slightly barbed, others smooth. Tibia I carries a long solenidion φ. Tarsus I with two solenidia viz., ω_1 and ω_2. Seta *pv'* slightly barbed, others smooth.

Material Examined

Holotype: ♀, paratypes: five ♀♀ and four ♂♂ collected from soil and litter samples of the second study site at Kakkanchery.

Remarks

A comparison of the present species with other described species reveals its similarity with *H. pairathi* described by Aoki in 1965a. Both possess smooth prodorsal, notogastral, infracapitular, anal and adanal setae. But it differs from *H. pairathi* in the number and nature of notogastral bands, lateral prodorsal margin and in the presence of a prodorsal band. The unique features of *H. davisi* are

1. Eight notogastral bands, s_3 and s_4 fused.
2. Sensillus with 13-14 branches.

3. Lateral prodorsal margin with a median conical projection.
4. presence of a prodorsal band formed of 6-8 crescentic area porosae between setae *in*.

Superfamily : Lohmannoidea Grandjean, 1967
Family : Lohmanniidae Berlese,1916
Genus : *Heptacarus* Piffl,1963

Generic Diagnosis

Genital plates with transverse suture. Anal and adanal plates fused. Preanal plate broad. Two pairs of anal and five pairs of adanal setae present. Pygidium with neotrichy. Twenty seven to sixty pairs of notogastral setae present. Epimeral region with weak neotrichy.

***Heptacarus indicus* sp. nov**
(Plates-34, Figs. 1-2, Plate- 35, Figs. 1-6)

Colour : Yellowish brown
Measurements : Length: 650 (Range 644-660)
Width : 382 (Range 372-388)

Dorsal Region (Plate-34, Fig. 1)

Body thick and flat. Anterior end roughly triangular. Posterior end oval. Integument densely punctate which follows a reticulate pattern.

Prodorsum

Prodorsum broader than longer. Posterior border slightly concave laterally. Rostrum downwardly flexed anteriorly. All prodorsal setae

barbed. Seta *ro* inserted well below the rostral apex, measuring 82 in length. Seta *le* inserted below *ro* and measures 90. Setae *exa* and *exp* curved upwards and measure 67. Seta *in* resembles *le* in appearance and with the same length and inserted slightly above *bo*. Bothridium with lateral opening. Sensillus (Plate-35, Fig. 2) pectinate with 18-20 longer anterior and 10-12 much shorter posterior barbs. Central rachis thickened medially. The entire prodorsal surface densely punctate which follows a reticulate pattern of arrangement.

Notogaster

Notogaster elongated and cylindrical with well pronounced neotrichy. Anterolateral border of notogaster straight while posterior border rounded. Forty four pairs of notogastral setae present. Variations found in paratypes, ranged 42-46. All notogastral setae heavily barbed, slightly curved and without any schematic arrangement. Setae c_2 and c_3 inserted much below the level of c_1 and c_4. Fissure *im* visible dorsally. Surface ornamentation of notogaster strongly resembles that of prodorsum.

Lateral Region (Plate-35, Fig. 1)

The extreme postero-lateral region of prodorsum and antero-lateral region of notogaster produced into downwardly flexed flap like portion. Fissure *ia* located on the antero-lateral flap. This flap extends posteriorly as a thickened ridge and stops abruptly at about one fourth the distance of the notogaster away from its posterior apex. Fissure *ip* visible.

Ventral Region (Plate-34, Fig. 2)

Rutellum (Plate-35, Fig. 3) well developed with three teeth, middle one being smaller than the rest. Chelicerae (Plate-35, Fig. 4) stout and broad with movable digit bearing two and fixed digit bearing three stout teeth. Seta *chb* long and smooth. Pedipalp (Plate-35, Fig. 5) five segmented with a chaeototaxy of 0-2-0-3-9. Palpal segments ornamented with reticulated punctations. Setae on all segments barbed in various degrees. Palpal tarsus with two eupathidia, one solenidion four barbed and two smooth setae. Solenidion thick and blunt. Infracapitulum with four pairs of barbed setae viz., *a*, *h*, m_1 and m_2 (Plate-35, Fig. 3). Two pairs of simple pre-oral setae present. Epimeral setal formula 3-1-3-4. All setae barbed. A transverse slit divides genital plate into anterior and posterior halves, carrying five pairs of setae, arranged in an antiaxial row of four longer setae and paraxial row of six smaller setae. All these setae barbed. Preanal plate narrow with a slight median excrescence. Anal and adanal plates fused and carry two pairs of small barbed anal setae and five pairs of long barbed adanal setae. Fissure *ia* located horizontally outer to apodeme 3 and *ip* obliquely on the ventral plate. Ventral region ornamented with dense punctations arranged in a recticulum.

Legs

All legs monodactylous. Leg 1 (Plate-35, Fig. 6) with a chaetotaxy of 0-3-5-5-19. Leg segments ornamented with reticulated punctations. Seta *d* on femur plumose and others barbed on one side. Femur 1 with

ventral keel and ridge. Genu I with two solenidia σ_1 and σ_2. Seta *d* and *l'* plumose. Tibia I possesses a thick long solendion φ which tapers towards the tip. The remaining four setae variously barbed. Tarsus I with a single thick and blunt solenidion *ω*. The famulus *ε* seen at the base of *ω*. Setae *p'*, *p"* and *s* eupathidic. The remaining 14 setae barbed either unilaterally or bilaterally.

Material Examined

Holotype: ♀, paratypes: 14 ♀♀ and six ♂♂ collected from Chaliyam beach on 20.05.2001.

Remarks

The genus *Heptacarus* was erected by Piffl (1963) with the type species *H. notoneotrichus*. Since then seven more species have been described from different parts of the world. The present new species on comparison with other described species of *Heptacarus* shows a superficial similarity to *H. supertrichus* Piffl (1967) in exhibiting pygidial neotrichy and also in the nature of notogastral setae, but *H. supertrichus* possesses 60 pairs of notogastral setae while *H. indicus* possesses 44 pairs. Other differences include the barbed nature of infracapitular seta *a*, presence of posterior barbs on sensillus and epimeral setal formula of 3-1-3-3 in *H. supertrichus* and 3-1-3-4 in *H. indicus*. The unique features which help to detect the present new species are as follows:

1. Epimeral setal formula of 3-1-3-4.
2. Barbed nature of seta *a* of infracapitulum.

3. Forty four pairs of notogastral setae which are of the same length and with strong cilia.
4. Position of setae c_2 and c_3 much below the level of seta c_1 and c_4.
5. Sensillus with 18-20 long braches on the anterior side and 10-12 minute spines posteriorly.
6. Integument with dense punctations arranged in a reticulate pattern.

Superfamily : Lohmannoidea Grandjean, 1967
Family : Lohmanniidae Berlese, 1916
Genus : *Javacarus* Balogh, 1961

Generic Diagnosis

Genital plates undivided, without transverse suture, usually with 10 pairs of setae. Anal and adanal plates fused. Preanal plate wide. Anal setae absent, four pairs of adanal setae present. Notogastral and epimeral region without neotrichy.

***Javacarus minutus* sp nov.**
(Plate-10, Fig. 4, Plate-36, Figs. 1-7)

Colour : Yellowish brown
Measurements : Length : 552 (Range: 544-588)
Width : 288 (Range: 264-298)

Dorsal Region (Plate-36, Fig. 1)

Body cylindrical with conical anterior and oval posterior ends. Lateral margins wavy. Body surface exhibits small tubercles, more prominent on prodorsum and posterior region of notogaster.

Prodorsum

Prodorsum triangular in outline with smooth rounded tip. Rostral tectum entire and well projected. All prodoral seate well foliate and smooth except seta *le*. Seta *ro* 84 long, directed forward and placed well behind the rostral tip. Seta *le* with very fine barbs, inserted behind and slightly lateral to *ro* and 96 long. Seta *exa* as long as *le*. Seta *exp* 84 long and directed laterally. Seta *in* inserted behind the *bo* but slightly towards the centre and measures 96. Bothridium small. Sensillus (Plate-36, Fig. 3) pectinate with 11-12 branches. A chain of 10 area porosae seen just below the insertional points of *in*. All over the prodorsum except the lateral sides, circular and irregular polygonal ornamentations visible which become smaller in size towards the rostral tip.

Notogaster

Lateral and posterior margins of notogaster wavy. Notogastral bands 10 in number, each formed of circular or oval area porosae of varying size, arranged very close to each other, s_2 and s_5 incomplete, s_{10} domb shaped. In between notogastral bands occur circular and oval tubercles which become prominent towards the posterior region. Sixteen pairs of foliate notogastral setae present. All notogastral setae smooth except ps_1 and ps_3 which appears slightly barbed. Marginal setae longer. Seta ps_1 smallest, 60 long with a definite bent towards the tip. Seta ps_2 longest, 108 long, c_3 102. Others range in size between 72 and 96. Ornamentation of notogaster similar to that of prodorsum.

Ventral Region (Plate-36, Fig. 2)

Rutellum (Plate-36, Fig. 4) sclerotised with blunt teeth. Two pairs of small and simple adoral setae seen very close to rutellum. Chelicerae (Plate-36, Fig. 5) with strong and well sclerotised digits, movable digit carries two prominent blunt teeth while fixed digit carries three. Setae *cha* and *chb* small and smooth. Pedipalp (Plate-36, Fig. 6) five segmented with a chaetotaxy of 0-1-0-0-11. Palpal tarsus bears a single solenidion (ω). Seta *su* long and tapering towards the tip while all others simple. Infracapitulum bears four pairs of setae; *a*, m_1, m_2 and *h*. All these setae smooth and of the same size. A group of four rosette shaped area porosae seen in the central area between setae *h*. Epimeral boundaries distinct. Epimeral setal formula 3-1-3-4. All setae smooth. Epimere 1 carries larger area porosae. Each genital plate bordered by triangular aggenital plate at its anterolateral corner. Genital plates entire without transverse suture. Each genital plate carries 10 smooth setae arranged in an antiaxial row of four and paraxial row of six. Paraxial setae small while antiaxial setae longer and slightly foiliate. Preanal plate broad, much broader than longer, its lateral edge slightly curved upwards. Anoadanal plates completely fused and carries four pairs of adanal setae. All these setae slightly foliate with smooth margins. Anal setae absent. Fissures *ia* and *ih* clearly visible on the ventral side. A few rounded and oval tubercles seen scattered along the ventro-lateral margin and also on the posterior side.

Legs

All legs monodactylous. Chaetotaxy of leg I (Plate-36, Fig. 7) 0-4-4-4-16. Femur I exhibits sclerotised ridges. Fine globular markings seen on the integument. Setae *l″* and *bv* on femur I highly foliate with well pronounced toothed edge. Genu I bears a solenidion σ inserted very close to *d*. Tibia I bears two well foliate setae with barbed margin, *l″* and xt_2, a simple seta l′ and a solenidion φ. Tarsus I carries two solenidia ω_1 and ω_2. Seta *m* eupathidic, famulus ε close to ω_2

Material Examined

Holotype: adult ♀ paratypes: six ♀♀ and one ♂ collected from Calicut University campus on 4.9.2000.

Remarks

The genus *Javacarus* was erected by Balogh (1961) with *J. kuhnelti* as type species. Currently the genus includes seven described species. The present species on comparison with previously described species reveals similarity with *J. reticulatus* described by Sengbusch (1982b) in the wavy nature of lateral and posterior margins of notogaster. However, it can be easily distinguished by the following features:

1. Smaller size of the body.
2. 10 rows of notogastral bands, s_2 and s_5 incomplete
3. Smooth nature of prodorsal and notogastral setae except *le*, ps_1 and ps_3.
4. Wavy nature of lateral and posterior margins of notogaster.

Superfamily : Lohmannoidea Grandjean, 1967.
Family : Lohmanniidae, Berlese, 1916.
Genus : *Vepracarus* Aoki, 1965.

Generic Diagnosis

Genital plates with transverse suture. Anal and adanal plates separated at their anterior part. Preanal plate narrow. Two pairs of anal and four pairs of adanal setae present. Pygidium with strong neotrichy. Neotrichial setae arboriform or ramified.

***Vepracarus arboriformes* sp.nov.**
(Plates- 37, Figs.1-2, Plate-38, Figs. 1-5)

Colour : Golden yellow.
Measurements : Length : 298 (Range 298-305)
Width : 130 (Range 130-135)

Dorsal Region (Plate-37, Fig. 1)

Body slender and elongated with conical anterior and oval posterior ends. Integument densely porose with spherical or crescentic tubercles.

Prodorsum

Prodorsum broader than longer with an entire rostral tectum, anteriorly. Lateral prodorsal margin with an angular projection just anterior to the level of seta *exa*. Seta *ro* plumose and inserted on a convex horizontal ridge present on the rostrum and measures 45. Seta *le* situated slightly below and lateral to the level of *ro* and measures 28. Seta *exa* with long barbs towards the base and small barbs towards the

tip, measures 28. Seta *exp* with smaller barbs and 42 long. Seta *in* 42 long with 2-3 barbs on one side and inserted very close to *bo*. Bothridium opens `laterally from which sprouts a strongly pectinate ss (Plate-38, Fig. 1), carrying 12-13 branches anteriorly and 6-8 short spine like branches posteriorly. Anterior barbs short proximally and increase in length distally. Central rachis thickened except at its proximal part. Prodorsal integument densely porose with spherical tubercles towards the centre and crescentic tubercles along the prodorsal margin.

Notogaster

Notogaster cylindrical with oval posterior end, margin slightly wavy. Dorsosejugal suture slightly concave. Pygidial neotrichy conspicuous. All setae except the 4 median pairs viz., c_1, d_1,e_1 and f_1 branched. Median setae simple. Pygidial neotrichial setae with 4-5 branches arising from the point of insertion of setae. Ornamentation of notogaster resembles that of the prodorsum.

Ventral Region (Plate-37, Fig. 2)

Rutellum (Plate-38, Fig. 2) well developed with three teeth, the middle tooth simple while the outer ones produced into two prominent knobs. Chelicerae (Plate-38, Fig. 3) with two blunt and stout teeth on the movable digit and three on the fixed digit. Both setae *cha* and *chb* present, *cha* short, thin, rough and pointed towards tip, *chb* long, stout, smooth and with blunt end. Pedipalp (Plate-38, Fig. 4) five segmented with a chaetotaxy of 0-1-0-1-7. Infracapitulum with six pairs of setae viz., *a*. *h*. m_1, m_2 m_3 and m_4. Seta *a* simple, others except m_4 finely barbed, m_4

longer than the others and with fewer barbs. Epimeral neotrichy present with setal formula 5-4-3-4. All setae on epimeres barbed and of different size. Setae *2b, 2c, 2d, 3b* and *3c* longer than the others. Sejugal apodemata well developed. A triangular aggenital plate present on the anterolateral corner of genital plate. Genital plates divided into two unequal parts by a transverse suture. The upper part small and narrow, lower part big and broad. A total of 10 setae present on each plate arranged in two rows, five on the anterior and five on the posterior half. All setae barbed. Preanal plate thin and wide with a median posterior extension. The suture between anoadanal plate gradually disappears towards the posterior end. Anal plates carry two pairs of barbed setae and adanal plates bear four pairs of bigger and barbed setae. Barbs more pronounced on the adanal setae. Fissure *ia* located ventrally below and outer to the level of sejugal apodeme and *ip* at the level of preanal plate laterally. Integument of ventral region slightly porose.

Legs

All legs monodactylous. Chaetotaxy of leg I (Plate-38, Fig. 5) 0-5-5-4-19. Femur I stout with a ventral ridge and a dorsal notch. All setae on femur I plumose. Genu I with two solenidia σ' and σ''', of which σ^{I} very long and tapering but σ'' short and tapering. Seta *d* closely associated with σ', *l'* plumose, *l''* smooth. Tibia I with a long solendiion φ. Both setae xt_1 and xt_2 plumose, l' smooth. Tarsus I with an apical pretarsus and a ventrally toothed stout claw. Tarsus I bears a blunt thick solenidion w_1 with a closely associated famulus ε at its base. The second

solenidion w_2 longer but thinner. Setae *s* and *m* eupathidic. Setae *tc* and *ft* with roughened surface.

Material Examined

Holotype: ♀, paratypes: two ♀♀ collected from bamboo grove, Calicut University Campus, Kerala, India on 8-9-2001.

Remarks

The genus *Vepracarus* was erected by Aoki (1965a) with *V. hirsutus* as type species and at present includes nine described species. The specimen collected during the present study when compared with earlier known species revealed its resemblance to *V. incompletus* described by Mahunka (1985) in the nature of the anal and adanal plates which are separated only in their anterior part and the arboriform nature of pygidial setae. But the presence of a very weak suture towards the posterior end is characteristic of the new species. Notogastral setae c_1, d_1, e_1 and f_1 thin and spinous in the present species but branched in *V. incompletes* with 2-4 long branches on each side of their basal half while apical half smooth. The nature of adanal setae distinct from that of *V. incompletes,* as it possess barbed adanal setae. The new species can be distinguished from all other described species of *Vepracarus* by the following features.

1. Smooth nature of notogstral setae c_1, d_1, e_1, and f_1.
2. Ano-adanal plates completely separated anteriorly and the suture becomes vague towards the posterior end.
3. Epimeral setal formula of 5-4-3-4.

4. Infracapitulum with 6 pairs of setae
5. Barbed nature of adanal setae.
6. Body surface densely porose with spherical or crescentic tubercles along the margin of prodorsum and pygidium

Vepracarus ramaniae sp.nov.
(Plate-10, Fig. 5, Plate-39, Figs.1-2, Plate-40, Figs.1-5)

Colour : Brownish yellow.
Measurements : Length : 510 (Range 495-520)
Width : 217 (Range 210-225)

Dorsal Region (Plate-39, Fig. 1)

Body very much elongated and straight sided. Anterior end slightly conical while posterior end rounded. Microsulpture of integument consists of round to oval porose excrescence which become crescentic towards the margin.

Prodorsum

Prodorsum as long as broad. Rostral tectum entire. Lateral prodorsal margin with characteristic angular projection just above the level of seta *exa*. All prodorsal setae plumose. Seta *ro* 75 long, inserted well below the rostral apex. Seta *le* 45 long, situated below and exterior to *ro*. Seta *in* 68 long, inserted very close to *bo*. Setae *exa* and *exp* 60 and 68 long respectively, inserted along the lateral prodorsal margin. Bothridium opens laterally downwards. Sensillus (Plate-40, Fig. 1) with 4-5 spine like branches towards the base and 10-12 long branches on one side and short spine like branches on the other side. Prodorsal

integument ornamented with round to oval porose excresence upto the level of bothridium. Below that integument exhibits dense punctations.

Notogaster

Notogaster more or less cylindrical with a wavy posterior end. Dorsosejugal suture prominent, almost straight. Pygidial neotrichy very weak. All notogastral setae branched, lateral setae longer than central ones carrying 5-7 branches on one side. Median setae plumose with 4-7 short branches. Pygidial neotrichial setae b_1 and b_2 smaller than the others with 4-5 branches originating from the base. Ornamentation of the integument of notogaster shows close similarity to that of anterior part of prodorsum with round to oval porose excrescence towards the middle and crescentic tubercles along the lateral and posterior margins.

Ventral Region (Plate-39, Fig. 2)

Rutellum (Plate-40, Fig. 2) with three well developed teeth, median one simple with rounded tip while the lateral ones notched. Chelicerae (Plate-40, Fig. 3) with two teeth on digitus mobilis and three on digitus fixus. Seta *chb* long but simple, and *cha* small and finely barbed. Pedipalp (Plate-40, Fig. 4) five segmented with a chaetotaxy of 0-1-0-1-7. Labiogenal articulation stenarthric type. Infracapitulum bears six pairs of setae viz., *a*, *h*, m_1, m_2, m_3 and m_4. Seta *a* simple and smooth, m_1 and m_2 barbed on one side, others with barbs on both sides. Two pairs of simple oral setae present above the level of *a*. Sejugal apodemata well developed. Epimeral neotrichy present with setal formula 6-3-3-3. All setae on the epimeres barbed, the median ones slightly smaller. A

triangular aggenital plate present at the antero-lateral corner of genital plate. Genital plate divided into two unequal parts by a transverse suture, the upper part small and narrow, lower part large and broad. Each genital plate carries 10 setae arranged in two rows, five on the anterior half and five on the posterior half. All setae barbed. Preanal plate thin with a prominent median posterior extension. Anal and adanal plates separated only in the anterior part, the suture gradually becoming faint and disappearing posteriorly. Two pairs of anal and four pairs of adanal setae present, all setae barbed. Anal setae smaller than the adanal ones. Ventral plate lying outer to anoadanal plate carries heavy punctation and foveloae.

Legs

All legs monodactylous. Integument of legs ornamented with dense punctations. Chaetotaxy of leg I (Plate-40, Fig. 5) 0-5-5—5-17. Femur I stout with a notch along ventral side. All setae on femur I plumose. Genu I with two solenidia σ' and σ'', σ' longer than σ''. Seta *d* barbed on one side, inserted close to σ''. Setae *v* and *l'* simple and smooth. Tibia I with a long solenidion φ. Setae *d* and xt_1 barbed on one side; xt_2 and *l'* smooth and simple. Tarsus I with an apical pre-tarsus bearing a stout claw. Tarsus I bears two solenidia w_1 and w_2, w_1 much longer with a closely associated famulus ε. Setae *s* and *m* eupathidic.

Material Examined

Holotype: ♀, paratypes four ♀♀ and two ♂♂ collected from Kakkanchery on 7-8-2001.

Remarks

The present species *V. ramaniae* on comparison with other previously known species is found to exhibit close resemblance to *V. cornutus* described by Sarkar and Subias (1984) in the possession of a short conical projection on the lateral margin of prodorsum close to seta *exa* and in the nature of prodorsal and notogastral stetae. But *V. ramaniae* can be distinguished from *V. cornutus* in the incomplete separation of anal and adanal plates, the nature of sensillus and epimeral setal formula. The present species can be distinguished from all other described species by the possession of certain unique features listed as follows:

1. Incomplete separation of anoadanal plates.
2. Sensillus with 4-5 spine like branches towards the base and 10-12 long branches distally.
3. Epimeral setal formula of 6-3-3-3.
4. Possession of very weak pygidial neotrichy.
5. Possession of densely porose round or oval excrescence on prodorsal and notogastral integument and crescentic tubercles along the lateral and pygidial margins of notogaster.

Superfamily : Lohmannodiea Grandjean, 1967
Family : Lohmanniidae Berlese, 1916
Genus : *Papillacarus* Kunst, 1959.

Generic Diagnosis

Genital plates with transverse suture. Anal and adanal plates separate. Preanal plate narrow. Two pairs of anal and four pairs of

adanal setae present. Pygidium with weak neotrichy. Epimeral region with weak neotrichy. Pygidial setae setiform, ciliate.

Papillacarus elongatus sp. nov.
(Plates-41, Figs. 1-2, Plate-42, Figs. 1-5)

Colour : Brownish yellow.
Measurements : Length: 638 (Range 631-638)
Width: 300 (Range 393-300)

Dorsal Region (Plate-41, Fig. 1)

Body moderately large, about twice as long as wide. Dorsal surface of body densely covered with fine granules grouped into polygonal masses, forming an imbricate pattern.

Prodorsum

Prodorsum with narrow, rounded tip and wavy margin. Prodorsal setae slightly thickened basally and finely pointed apically, ciliate on both sides. Seta *ro* thickened basally and bent inwards apically measuring 58 in length. Seta *le* directed outwards anteriorly, measures 73. Seta *exa* thinner, 82 long. Seta *exp* with thicker base and measures 87. Seta *in* slender measuring 76 in length. Bothridium bell shaped, directed laterally downwards. Sensillus thin, pectinate with 14-16 branches (Plate-42, Fig. 1). A transverse band present below the level of bothridium below which the integument carries uniformly arranged fine granules. Lamellar area clear without any ornamentation. The integument of prodorsum bears polygonal areas bearing minute area porosae.

Notogaster

Notogaster oval with rounded posterior end and smooth margins. Twenty five pairs of notogsteral setae consisting of the normal series as well as neotrichial ones present at the pygidial region. Central setae, c_1, d_1, e_1, f_1 and h_1 small, smooth and simple. Seta e_1 longer than the others which range in length between 40-48. Marginal setae longer with very fine cilia on either side and range in size between 72-96 in length. Neotrichial setae smaller than the marginal ones and densely ciliated. The entire surface of notogaster ornamented with polygonal areas carrying minute area porosae.

Ventral Region (Plate-41, Fig. 2)

Rutellum (Plate-42, Fig. 2) with three blunt teeth. Chelicerae (Plate-42, Fig. 3) strongly built, fixed digit with three and movable digit with two teeth. Setae *cha* and *chb* smooth and simple, the latter much more longer compared to the former. Pedipalp (Plate-42, Fig. 4) five segmented with a chaetotaxy of 0-1-1- 1-7. Labiogenal articulation stenarthric type. Infracapitulum bears six pairs of setae viz., *a*, *h*, m_1, m_2, m_3 and m_4. Setae small, barbed and curved towards the tip. Epimeral region with slight neotrichy with a chaetotaxy of 7-3-3-3. Setae 1*a*, 2*a*, 3*a*, 4*a* and 4*b* simple and small, others finely barbed. Triangular aggential plate present at the antero-lateral corner of the genital plate. A transverse suture divides the gential plate into upper smaller and lower larger halves. Ten pairs of genital setae present, arranged in two rows of four antiaxial and six paraxial setae. All setae smooth and simple, paraxial setae very small while antiaxial setae longer. Preanal plate very

narrow but with a definite median, posteriorly directed and bifurcated excrescence. Anal and adanal plates separated, the former with two and the latter with four pairs of setae. Anal setae sparsely barbed while adanal setae densely barbed. Fissure *ia* visible outer to epimere 3, *ih* near the posterior lateral margin of the body at the level of posterior end of genital plate. The ventral plate bears fine granular micro sculpture.

Legs

All legs monodactylous. Leg I (Plate-42, Fig. 5) with a chaetotaxy of 1-4-5-5-17. Trochanter I bears a single smooth seta. Femur I with a prominent notch basally. Setae *d*, *v*, and *l''* smooth and simple, *l''* ciliated. Genu I with two solenidia σ' and σ'' of which the latter much longer than the former. Setae *v* and *d* simple and smooth. Setae *l''* with toothed margin along its outer edge. Tibia I with a very long solenidium φ. Setae xt_1 and xt_2 similar with toothed margin while *v* and *l* smooth and simple. Tarsus I with two solenidia, ω_1 and ω_2. A famulus ε present closely associated with w_1. Setae *s* and *m* eupathidic. Setae (*p*) (*tc*) and (*u*) smooth with sharply pointed tip. All segments with porose integument.

Material Examined

Holotype: ♀, paratypes: six ♀♀ and two ♂♂ collected from litter and soil samples from Kakkanchery on 16-8-2001.

Remarks

Kunst (1959) erected the genus *Papillacarus* with *P. aciculata* (Berlese, 1905) as type species. The genus presently includes 13 species described from different parts of the world. Comparative studies on the

members of the genus *Papillacarus* show that the present species *P. elongatus,* resembles *P. chamartinensis* described by Perez-Inigo (1967) in the ornamentation of integument and nature of notogastral setae. However the present species can be easily distinguished from *P. chamartinensis* and other described species by the following characters.

1. Possession of a distinct transverse band across the prodorsum below the level of bothridium.
2. Presence of 25 pairs of notogastral setae.
3. Setae c_1, d_1, e_1, f_1 and h_1 smooth, others with very fine cilia on either side.
4. Infracapitulum with six pairs of barbed setae curved towards the tip.
5. Epimeral setal formula 7-3-3-3.
6. Chaetotaxy of leg I, 1-4-5-5-17.

Family : Otocepheidae Balogh, 1961
Subfamily : Otocepheinae Balogh, 1961
Genus : *Megalotocepheus* Aoki, 1965

Generic Diagnosis

Presence of median prodorsal candyle *co.pm,* apodemata I. Notogastral setae *ta* and *te* normally spaced, *te* inserted mid-distance between *ta* and *ti*. Five segmented palp.

Members of the family Otocepheidae posses certain taxonomically important characters not present in other oribatid mites. Prodorsum carries two pairs of condyles, a lateral pair (*co.pl*) and a median pair (*co.pm*). Each side of prodorsum bears a narrow plate like structure

situated laterally called lateral lamelliform expansions (*spa*). Two pairs of condyles present on the notogaster viz., median notogastral condyle (*co.nl*) and lateral notogastral condyle (*co.nm*). Close to bothridium occurs dorsal and ventral thickened plates called dorsal bothridial plate (*tbd*) and ventral bothridial plate (*tbv*). Lateral projection situated between leg II and leg III referred to as pedotecta complex (pd_2 and pd_3). Dorsally prodorsum bears an elongated part (*spd*) situated just posterior to pd_1 on each side, separated from the latter by a more or less distinct ridge. A dark coloured rounded orifice called epimeral foramen (*fep*) situated laterally on ventral surface between *pd*. Some pairs of week irregular ridges called inter lamellar wrinkles (*rin*) occurs medio-posteriorly on prodorsum. Smooth or undulating marginal ridge (*vm*) present around notogaster between the median convex part and marginal part. A short slit like aggenital fissure (*iag*) located antero-laterally to genital aperture on each side.

***Megalotocepheus glabrus* sp. nov.**

(Plate-43, Figs. 1-7)

Colour : Greyish black
Measurements : Length : 1410 (1328-1465)
Width : 620 (596-640)

Dorsal Region (Plate-43, Fig 1)

Body narrow and elongated with conical anterior and round posterior ends. Microsculpture of the integument consists of very fine punctations.

Prodorsum

Prodorsum slightly flattened on each side. Median part of prodorsum with a few wrinkles. *Spa 1* moderately developed, slightly broad towards its base, becoming progressively thin and narrow towards the anterior end. *spa* terminates well below the insertion point of seta *ro*. Tutorium poorly developed. Lamellae prominent. *tbd* conspicuous, slightly convex anteriorly. *tbv* broad. Seta *ro* inserted well below the rostral apex, measures 190 and with fine barbs. Seta *le* incurved, inserted slightly below the level of *ro* and a little above the proximal end of *spa 1*, distinctly barbed and measures 165. Both these setae thin and flagelliform towards the tip. Seta *exa* thin and smooth without barbs measuring 104. Seta *exp* longer than *exa*, 170 in length. Seta *in* as long as *ro* but smooth. Sensillus (Plate-43, Fig. 3) with long narrow pedicel and slender fusiform head. Interlamellar ridges well developed. co. *pl*. smoothly arched. co. *pm* rounded and well separated from each other. Pedotectum 1, well developed. *Spd* distinct. pd_2 and pd_3 visible in lateral view. pd_4 elongate and triangular in shape. Prodorsal integument with very fine punctations.

Notogaster (Plate-43, Fig. 1)

Notogaster oval in shape with straight border. *co. nl* elongated. Distance between *co.nl* on both sides 20 RLN on an average (range: 18~22 RLN) co. nm. absent. Marginal ridge *vm* well developed along the entire border of notogaster. Ten pairs of notogastral setae. All setae thin, smooth and with pointed tip except p_1 with blunt tip. Setae *ta, te, ti, m,* r_2

and p_1 range in size from 150-165. Seta r_3 longest measuring 210. Setae r_2, p_2 and p_3 measure 180-200. *gla* located at the level of seta *ti* but towards the lateral margin of notogaster. Five pairs of notogastral fissures present as narrow transverse or oblique slits. *ia* seen above *te*, *im* above *gla*, *ih* between *ms* and r_3, *ips* close to p_3 above its insertion point and *ip* between p_2 and p_3. Notogastral integument ornamented with fine punctations which become dense towards anterior mid-dorsal region.

Ventral Region (Plate-43, Fig. 2)

Labiogenal articulation stenarthric type and strongly convex towards the posterior side. Rutellum (Plate-43, Fig. 4) with three stout, rounded knobs, the middle one smaller. Chelicerae (Plate-43, Fig. 5) strong and thick, seta *chb* barbed and double the length of the smooth *cha*. Pedipalp (Plate-43, Fig. 6) five segmented with a setal formula 0-2-1-3-9. Infracapitulum with three pairs of smooth setae with pointed tips. Seta *h* flexed inwards, *a* and *m* straight. Epimeral regions well differentiated, apo_1, apo_2 clearly defined, apo_3 moderately developed while *apo*4 in the form of a thin ridge. Epimeral setal formula 3-1-3-3. All setae smooth, *1a*, *2a*, *3a* and *4a* small and curved. Others long and thin with pointed tips. *sj* distinct. Distance between genital and anal plates equal to more than double the length of genital plate. Genital plates dark coloured, trapezoidal in appearance bearing four pairs of thin, smooth and finely pointed setae. Aggenital fissures found as a very small pair of slits near the anterolateral corners of genital aperture. Aggenital seta *ag* long, thin smooth with pointed tip located midway between genital and aggenital plates. Anal aperture in the form of a long slit. Two pairs of

thin, smooth anal setae. Two pairs of smooth adanal setae, ad_1 smaller than ad_2. Fissure *iad* situated anterolateral to anal plate. Integument of the ventral region with closely distributed fine punctations.

Legs

All legs monodactylous. Tarsus and tibia of each leg fused together. Chaetotaxy of leg I, 0-3-4-17 (Plate-43, Fig. 7). Setae *v*, *l'* and *l"* on femur I long, thin and weakly barbed. Genu I bears a solenidion σ. Setae *d* and *l'* slightly barbed while seta l" smooth. Tarsus I with two solenidia, *ω*, flagelliform, ω_2 thicker with a bent tip. ε small and curved. Setae *pv* and *s* barbed. Others smooth.

Material Examined

Holotype: ♀, paratypes: six ♀♀, two ♂♂ collected from soil samples from the botanical garden in Calicut University on 10-5-2002.

Remarks

The genus *Megalotocepheus* was erected by Aoki (1965c) with *M. japonicus* as type species and at present consists of four described species. Comparative studies on the members of the genus *Megalotocepheus* with the present specimen show that it resembles *M. japonicus* Aoki (1965c) in the presence of short and narrow *spa1*, poorly developed tutorium, fusiform nature of sensillus, smoothly arched nature of co. pl. and nature of pedotecta. But the present specimen possesses some unique characters which help to distinguish it from other described species which are given below.

1. Well developed marginal ridge along the entire border of notogaster.
2. Smooth nature of sensillus.
3. Barbed nature of setae *ro* and *le*.
4. Smooth nature of notogastral, epimeral, genital, aggenital, anal and adanal setae.
5. Presence of two pairs of adanal setae with pointed tips, ad_1 smaller than ad_2.
6. Median prodorsal condyles separated from each other.

PLATE 19

Atropacarus (Hoplophorella) chaliensis sp. nov.

Fig. 1 Lateral view

Fig. 2 Dorsal view

Fig. 3 Bothridium and sensillus

Fig. 4 Rostral seta

Fig. 5 Lamellar seta

Fig. 6 Notogastral seta

PLATE 19

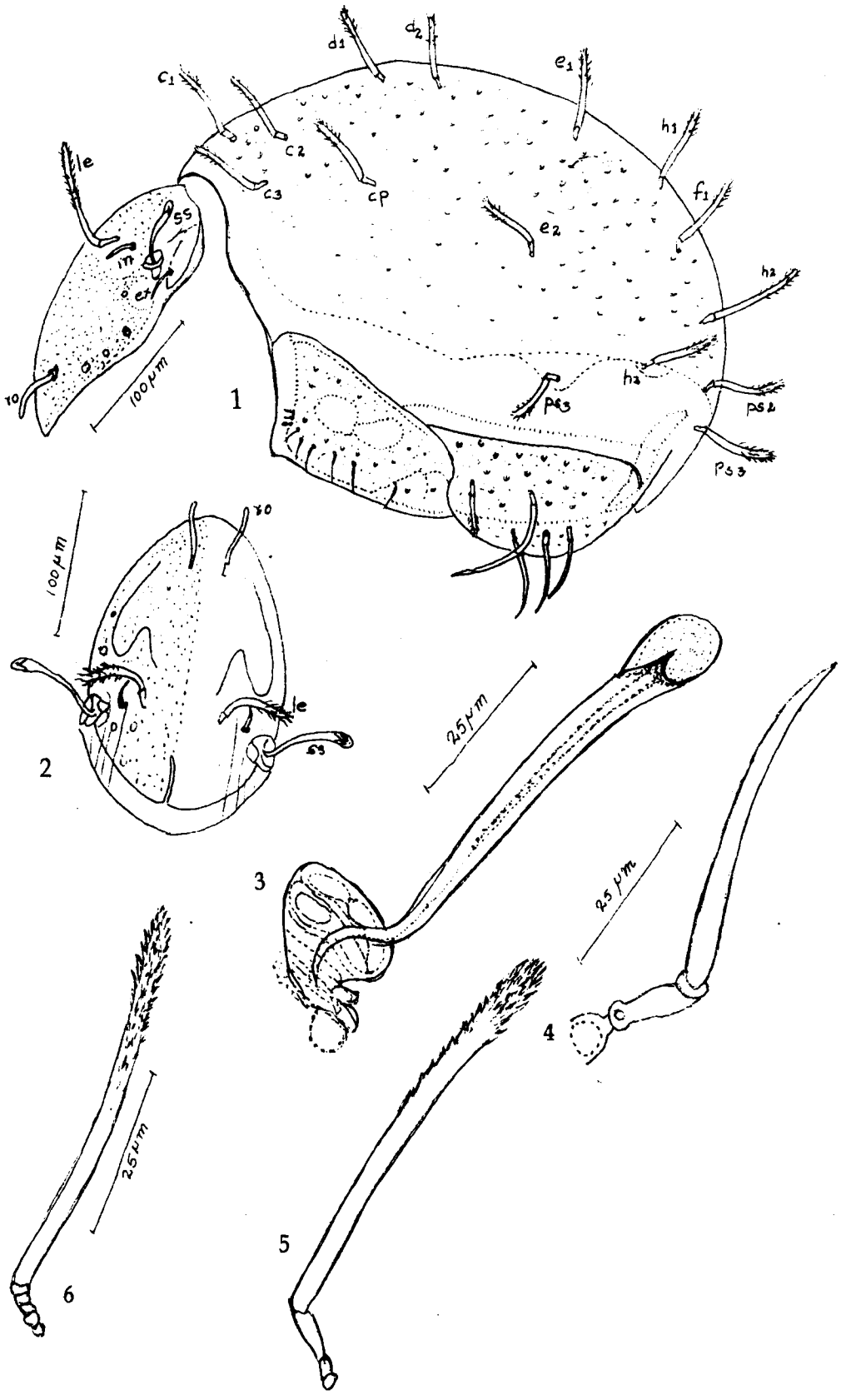

d1
d2
e1
c1
c2
c3
cp
e2
h1
f1
h2
le
ss
im
ex
ro
100 µm
1
ps3
ps2
ps3
2
25 µm
3
4
5
6

PLATE 20

Atropacarus (Hoplophorella) chaliensis sp. nov.

Fig. 1 Rutellum

Fig. 2 Chelicera

Fig. 3 Pedipalp

Fig. 4 Epimeral region

Fig. 5 Genital and ano adanal region

Fig. 6 Leg I

PLATE 20

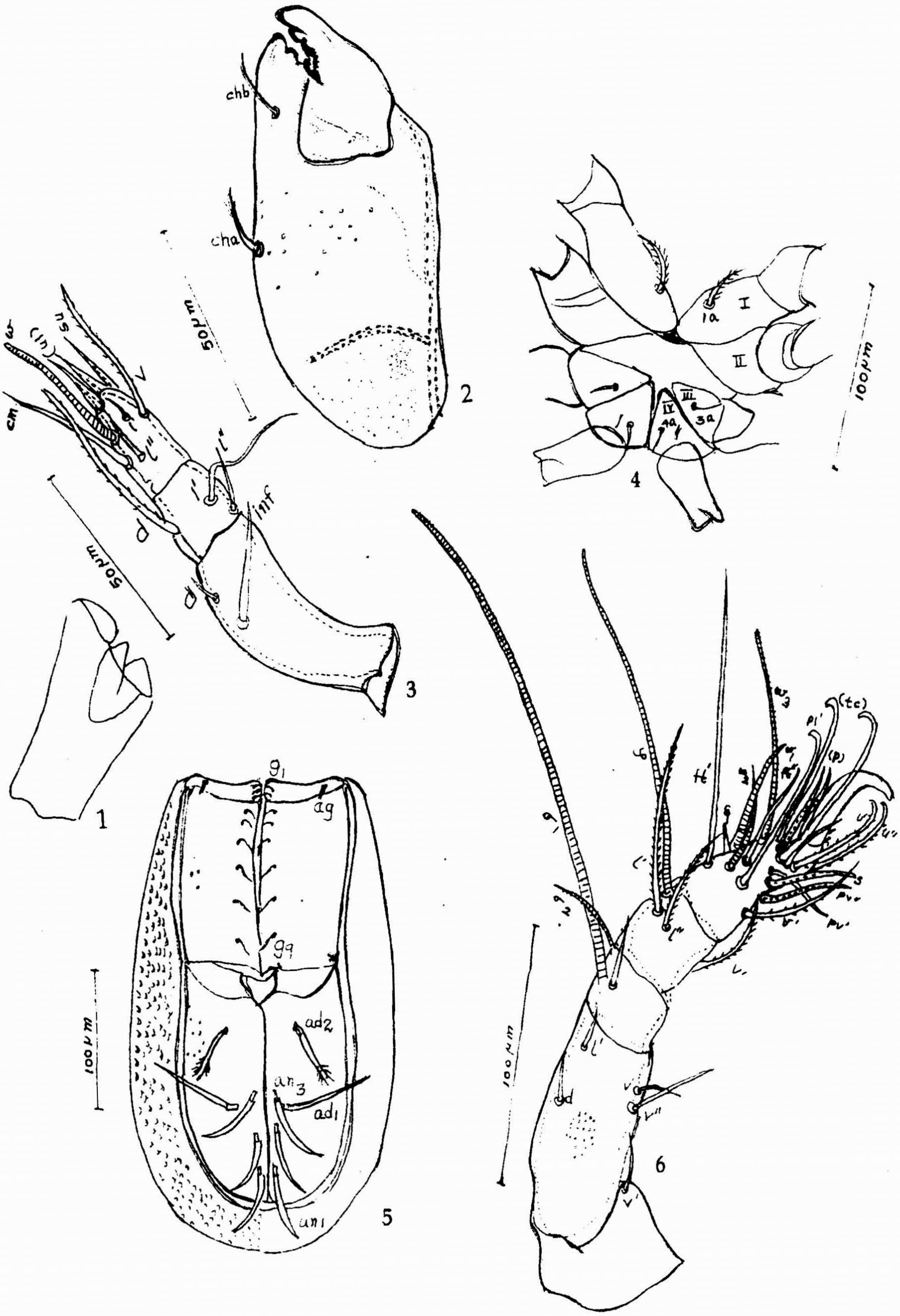

chb
cha
50 μm
2
su
v
cm
l''
l'
inf
d
50 μm
3
1
g1
ag
g4
ad2
an3
ad1
an1
100 μm
5
1a
I
II
III
IV
3a
4a
100 μm
4
ω3
(tc)
(p)
ft'
σ
d
l'
v'
v''
100 μm
6

PLATE 21

Atropacarus (Hoplophorella) crenulus sp. nov

Fig. 1 Lateral view

Fig. 2 Dorsal view of aspis

Fig. 3 Bothridium and sensillus

Fig. 4 Rutellum

Fig. 5 Chelicera

Fig. 6 Pedipalp

Fig. 7 Infracapitulum

Fig. 8 Epimeral region

Fig. 9 Genital and ano adanal region

Fig. 10 Leg I

PLATE 21

1
2
3
4
5
6
7
8
9
10
100 µm
25 µm
50 µm
ro
le
in
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c1
c2
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cp
d1
d2
e1
e2
f1
h1
h2
h3
ps1
ps2
ps3
ad1
ad2
an1
an3
ag
g4
g9
chb
cha

67

PLATE 22

Atropacarus (Hoplophorella) reticulatus sp. nov.

Fig. 1 Lateral view

Fig. 2 Dorsal view of aspis

Fig. 3 Enlarged view of notogastral seta

Fig. 4 Bothridium and sensillus

Fig. 5 Rutellum

Fig. 6 Epimeral region

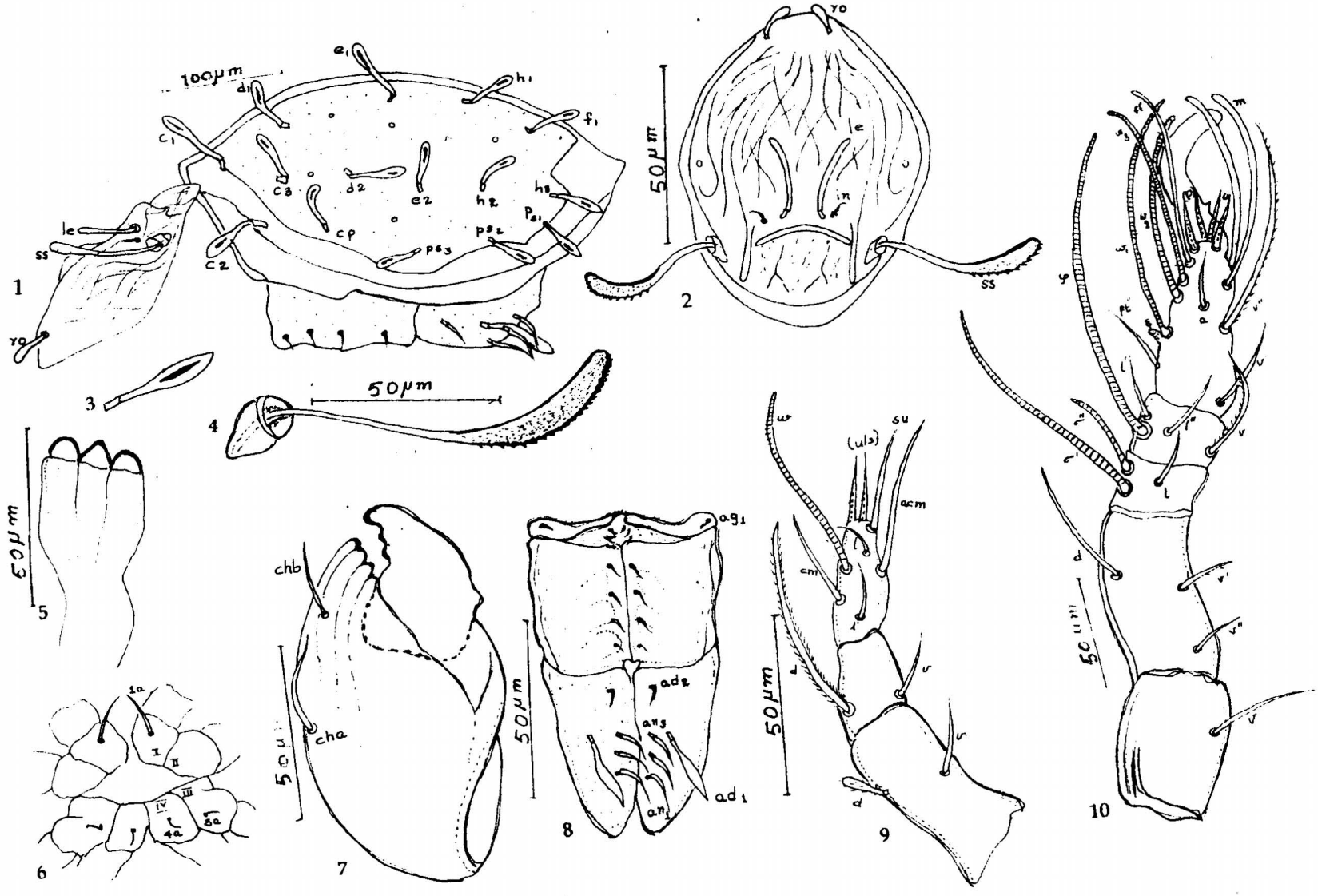
Fig. 7 Chelicera

Fig. 8 Genital and ano adanal region

Fig. 9 Pedipalp

Fig. 10 Leg . I

PLATE 22


100µm
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50µm
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1
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3
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5
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7
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9
10
ro
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le
chb
cha
ag1
ad1
adz
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(uls)
acm
cm

PLATE 23

Atropacarus (Hoplophorella) keralensis sp. nov.

Fig. 1 Lateral view

Fig. 2 Dorsal view of aspis

Fig. 3 Bothridium and sensillus

Fig. 4 Notogastral setae

Fig. 5 Notogastral setae

Fig. 6 Infracapitulum

Fig. 7 Chelicera

Fig. 8 Epimeral region

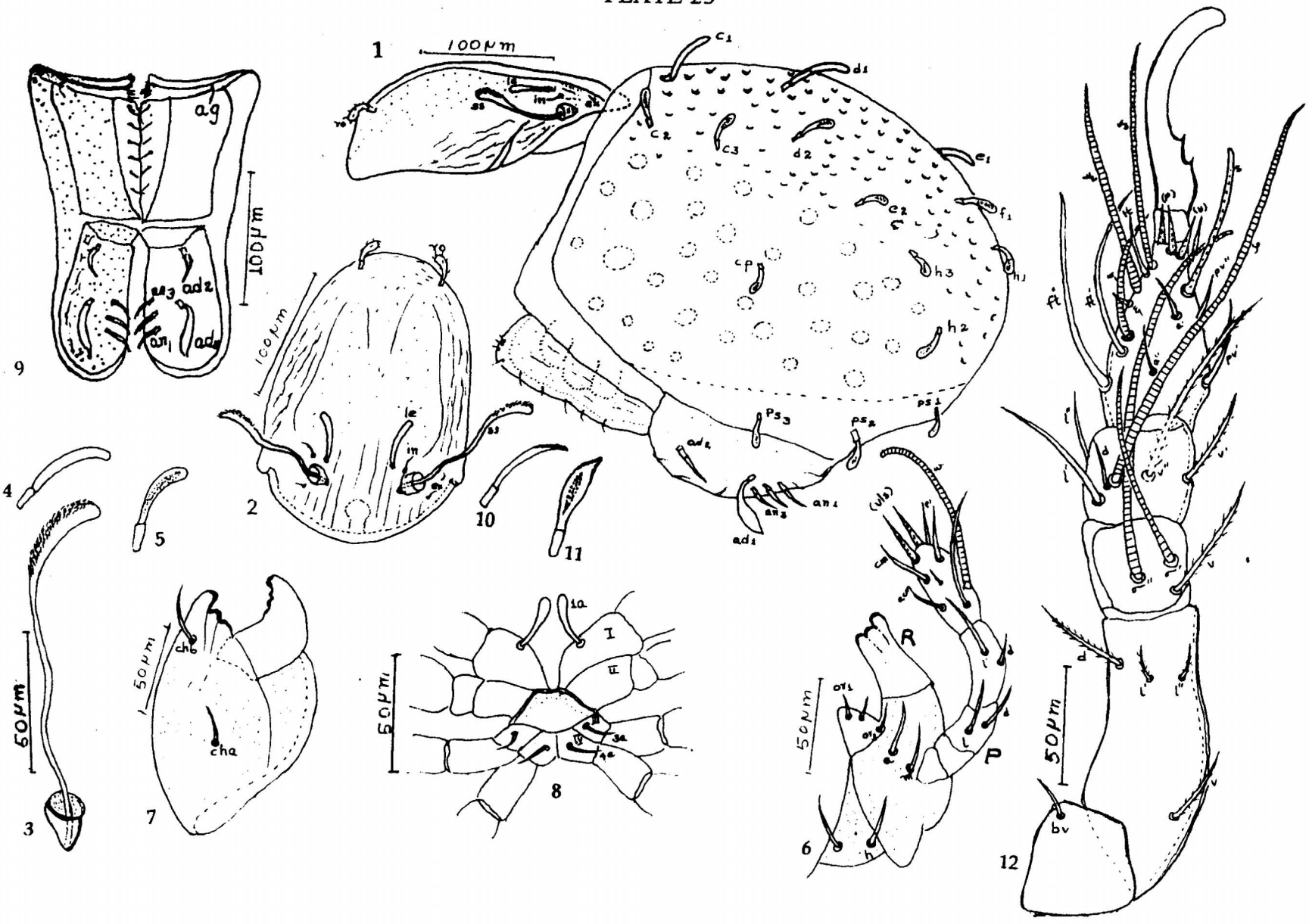
Fig. 9 Genital and ano adanal region

Fig. 10 Anal seta

Fig. 11 Adanal seta

Fig. 12 Leg I

PLATE 23


1
100µm
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50µm
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6
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7
50µm
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50µm
9
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10
11
12
50µm

PLATE 24

Phthiracarus haqi sp. nov.

Fig. 1 Lateral view

Fig. 2 Dorsal view of aspis

Fig. 3 Bothridium and sensillus

Fig. 4 Rutellum

Fig. 5 Chelicera

PLATE 24

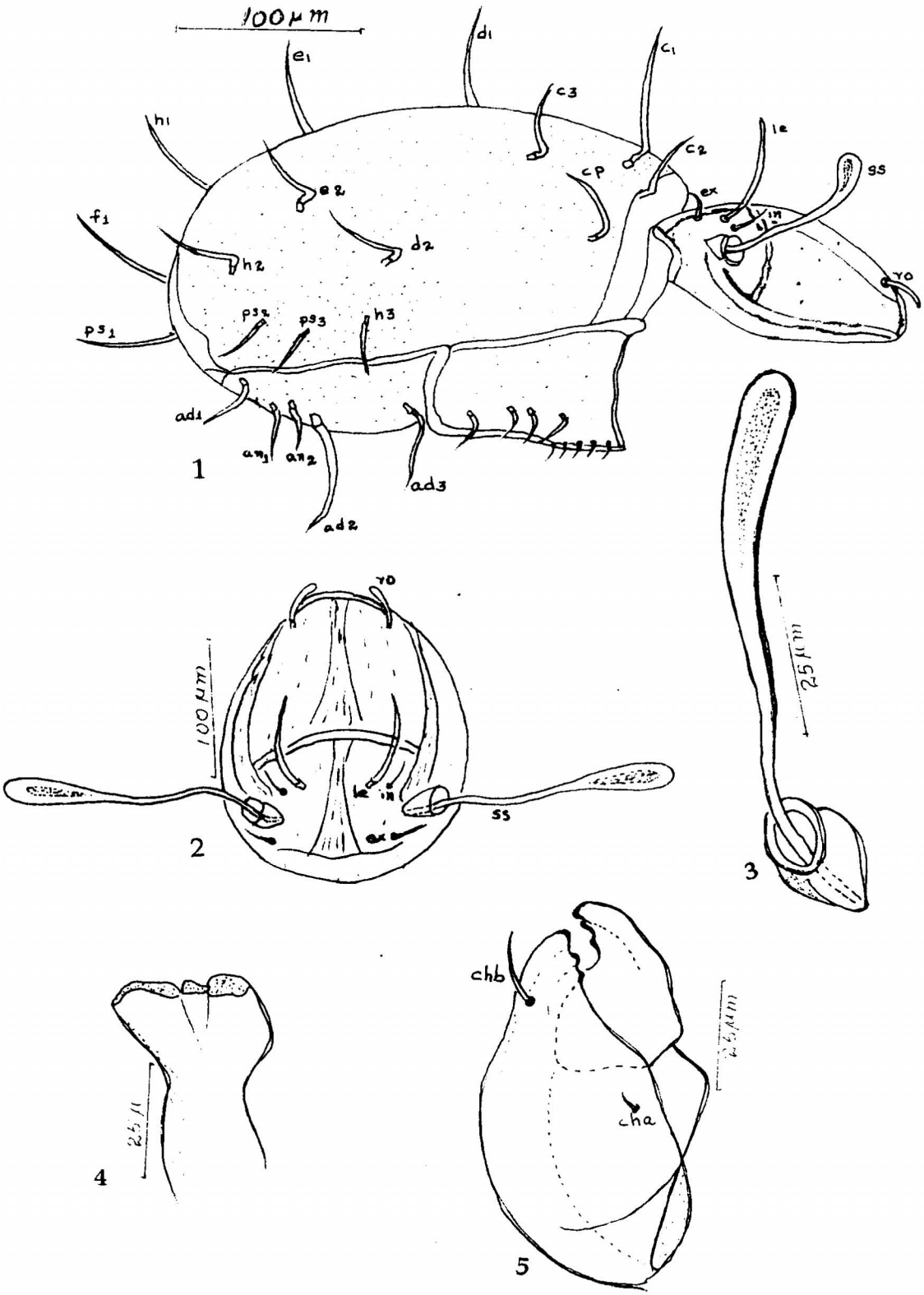

100 µm
e1
d1
c1
c3
h1
c2
1e
ss
cp
ex
e2
f1
d2
h2
ro
ps2
ps3
h3
ps1
ad1
am1
am2
ad3
ad2
1
ro
100 µm
ss
2
25 µm
3
25 µm
chb
cha
4
5

PLATE 25

Phthiracarus Haqi SP. NOV

Fig. 1 Pedipalp

Fig. 2 Epimeral region

Fig. 3 Genital and ano adanal region

Fig. 4 Leg. I

PLATE 25

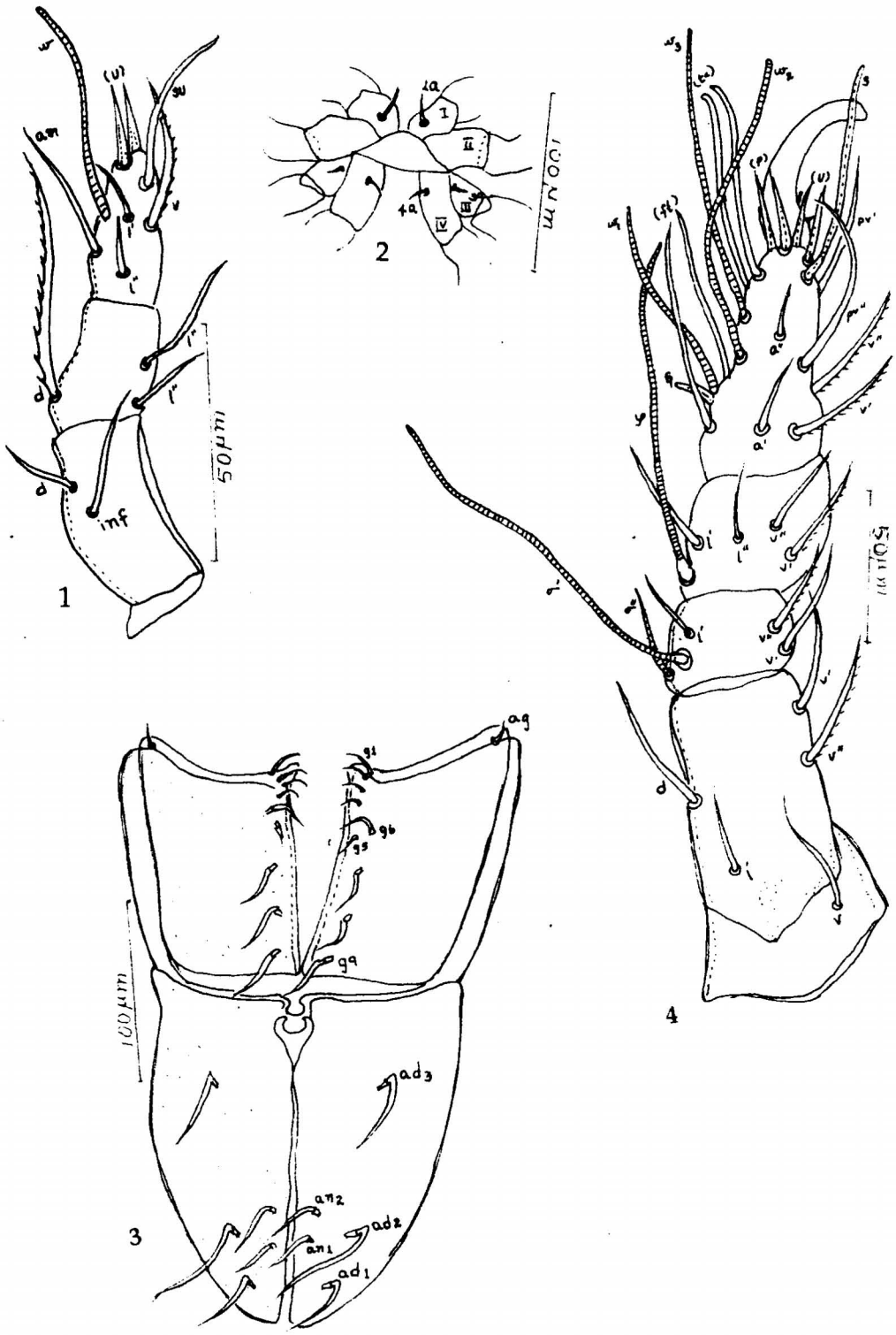


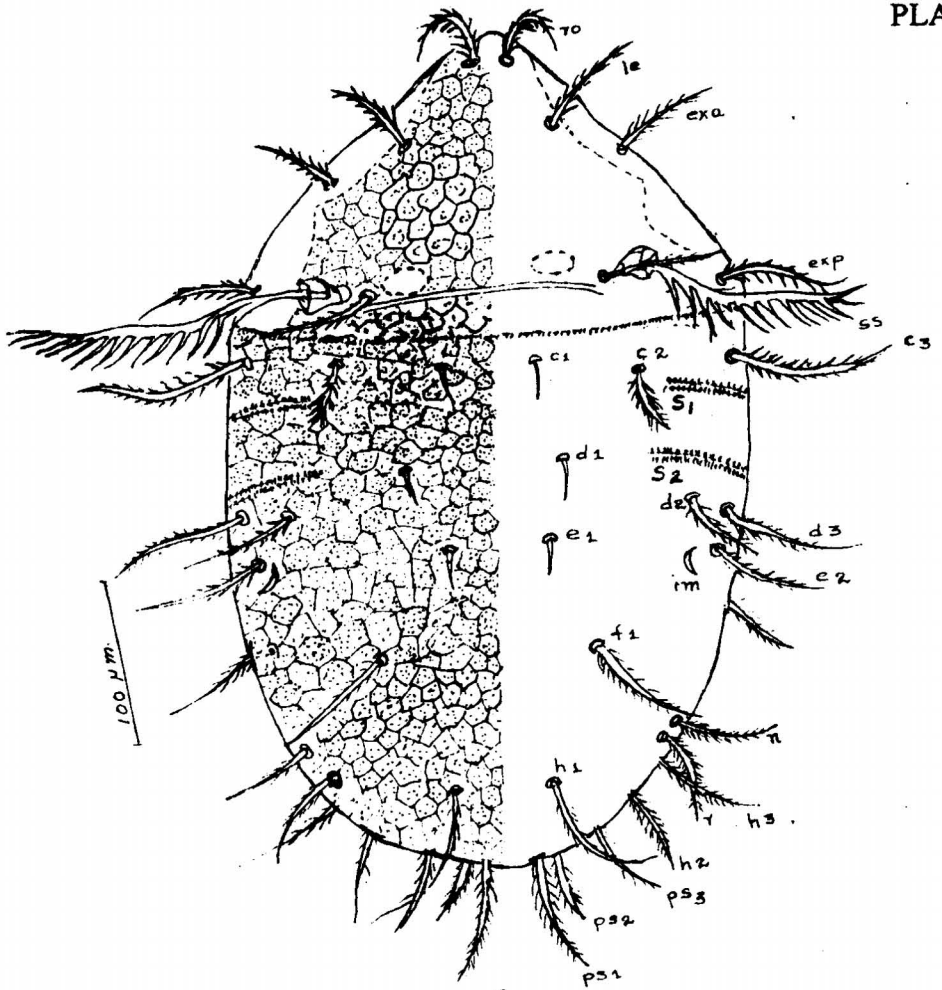
PLATE 26

Annectacarus malabaricus sp. nov.

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 26



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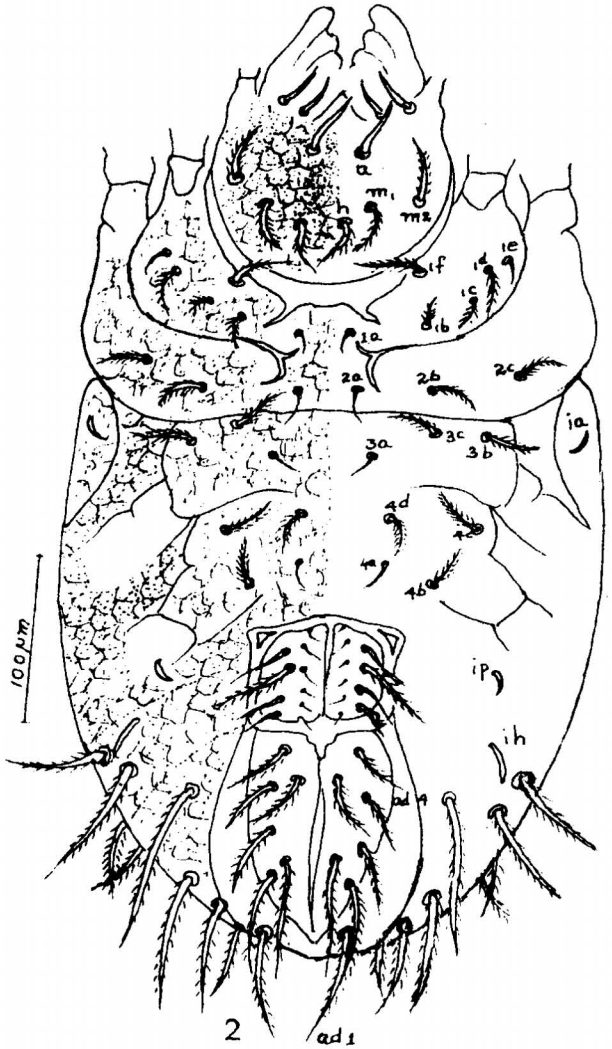


2 ad1

PLATE 27

Annectacarus malabaricus **sp. nov.**

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Infracapitulum

Fig. 6 Leg 1

PLATE 27

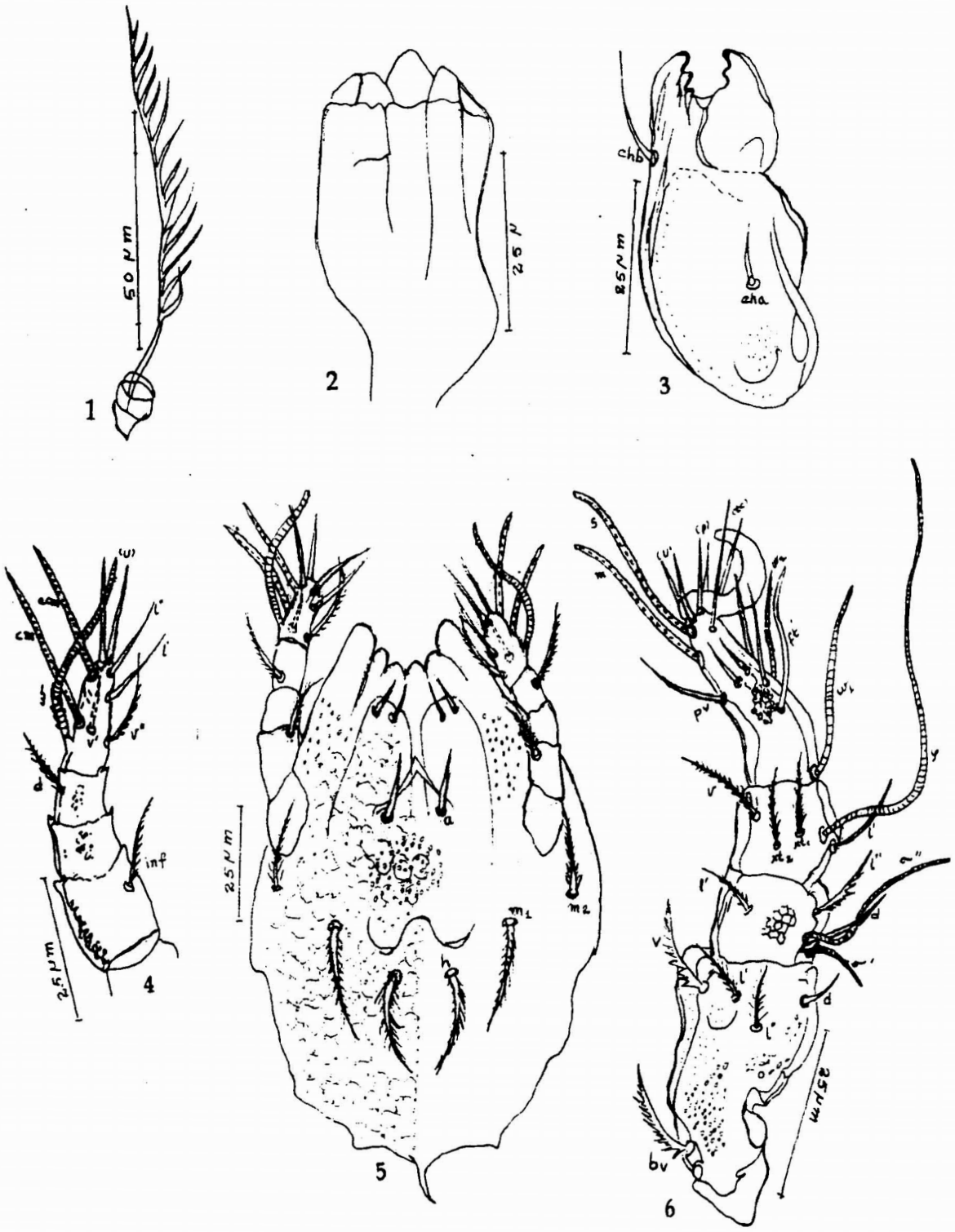


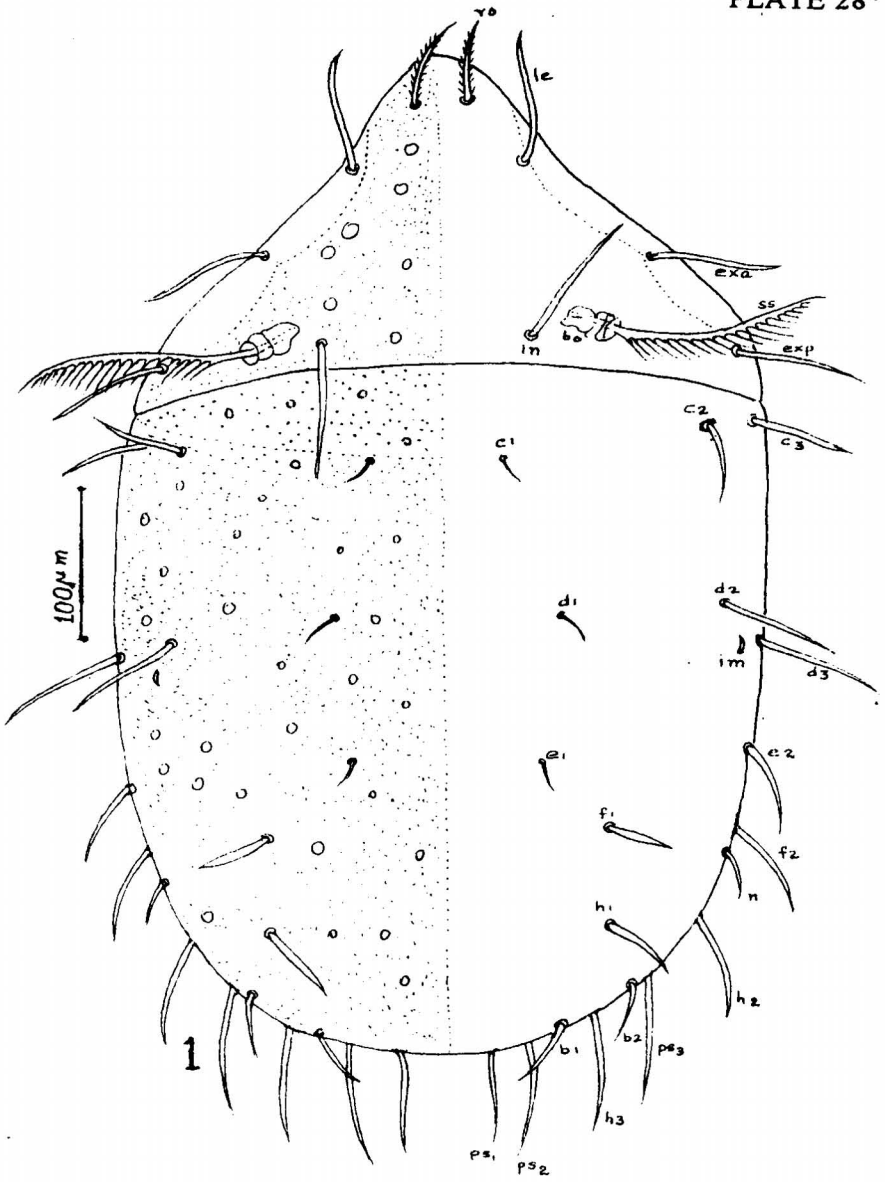
PLATE 28

Annectacarus plumosus SP. NOV.

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 28


100µm
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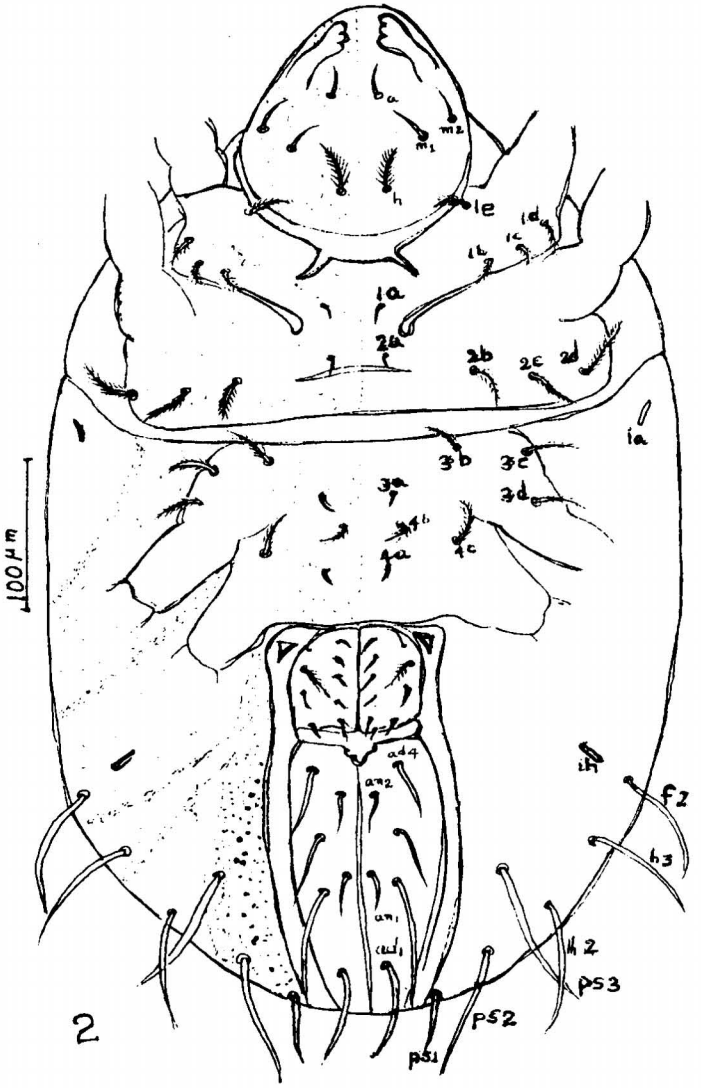
1


100µm
ba
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1c
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1
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3b
3c
3d
3a
4b
4a
4c
ia
ip
f2
h3
h2
ps3
ps2
ps1
2

PLATE 29

Annectacarus plumosus sp. nov.

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 29

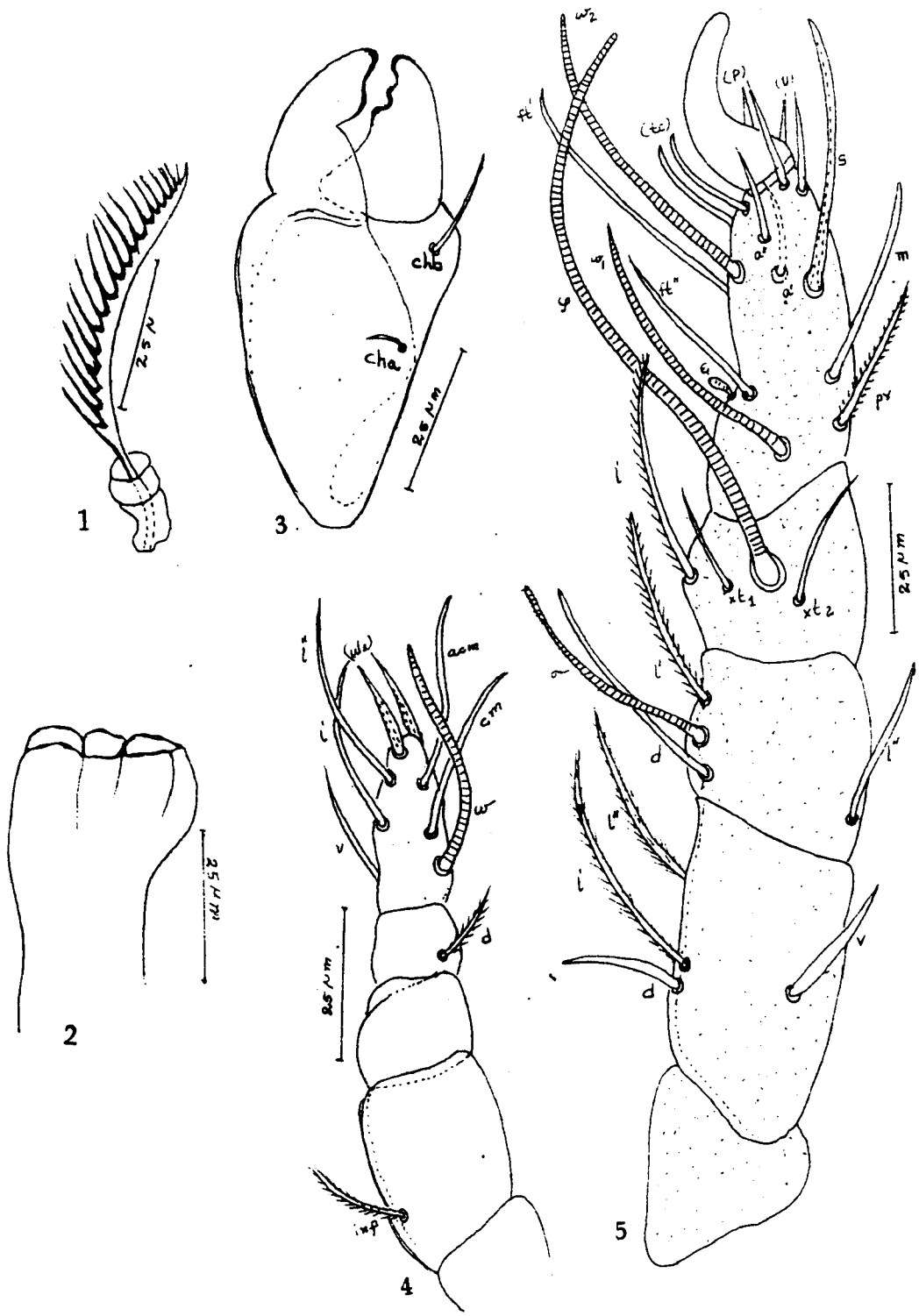


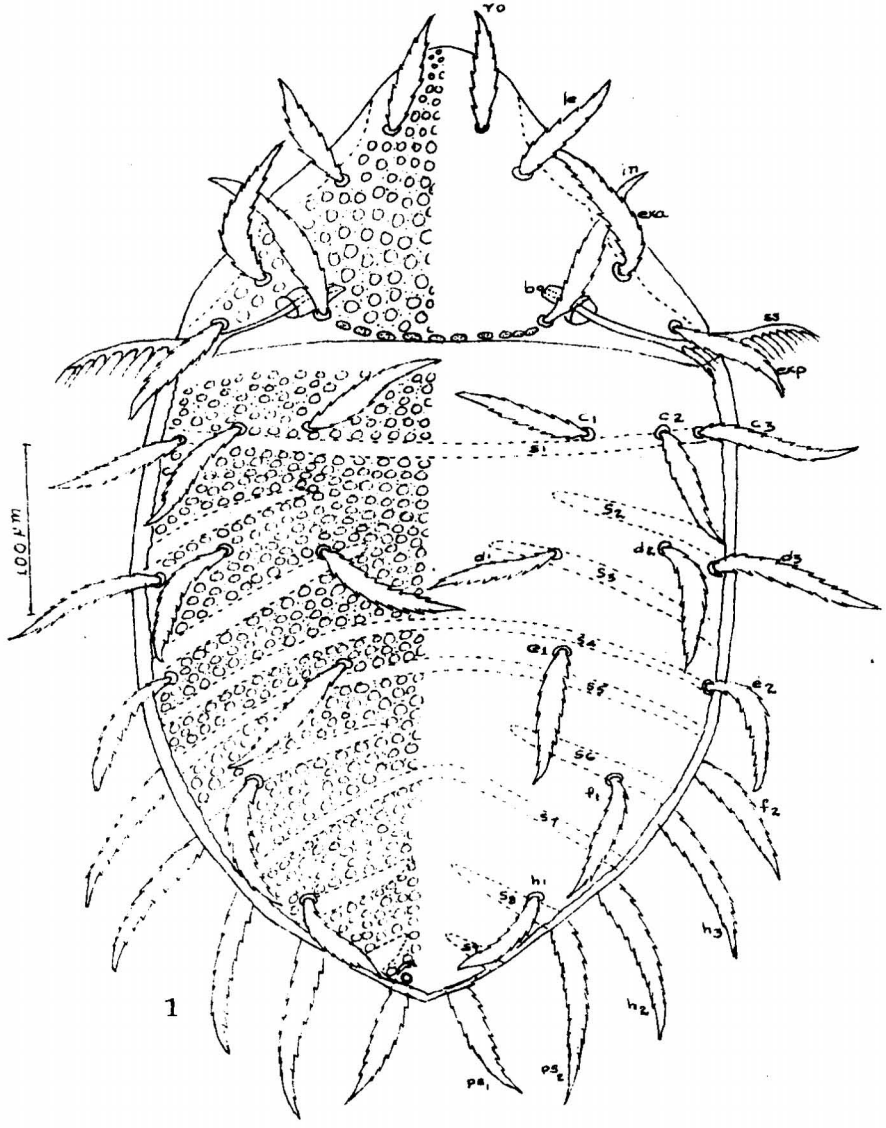
PLATE 30

Haplacarus xavieri sp. nov.

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 30



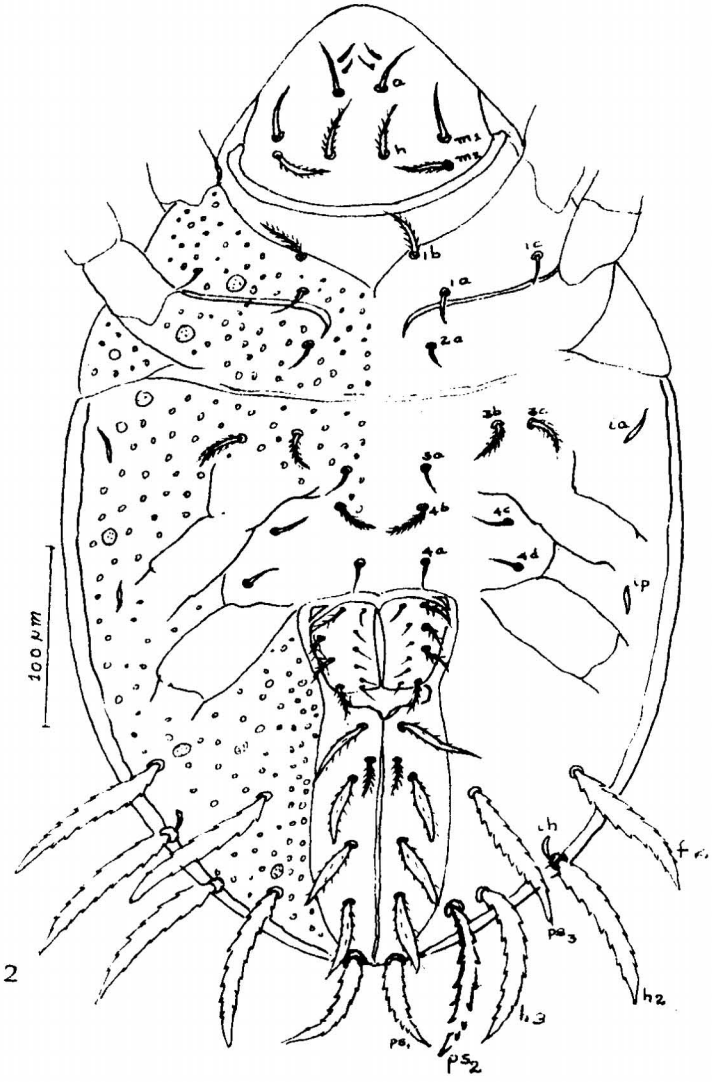


PLATE 31

Haplacarus xavieri sp. nov.

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 31

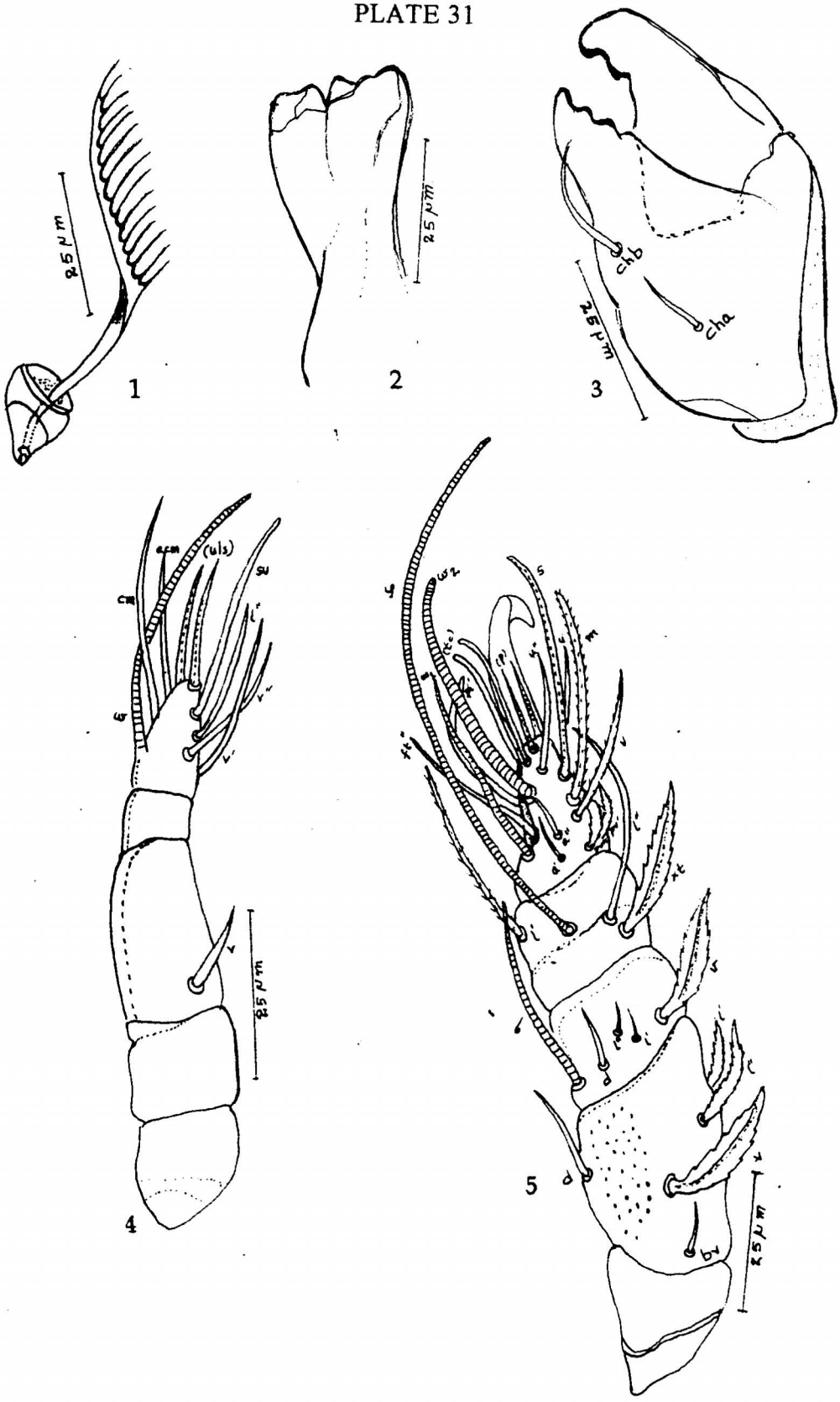


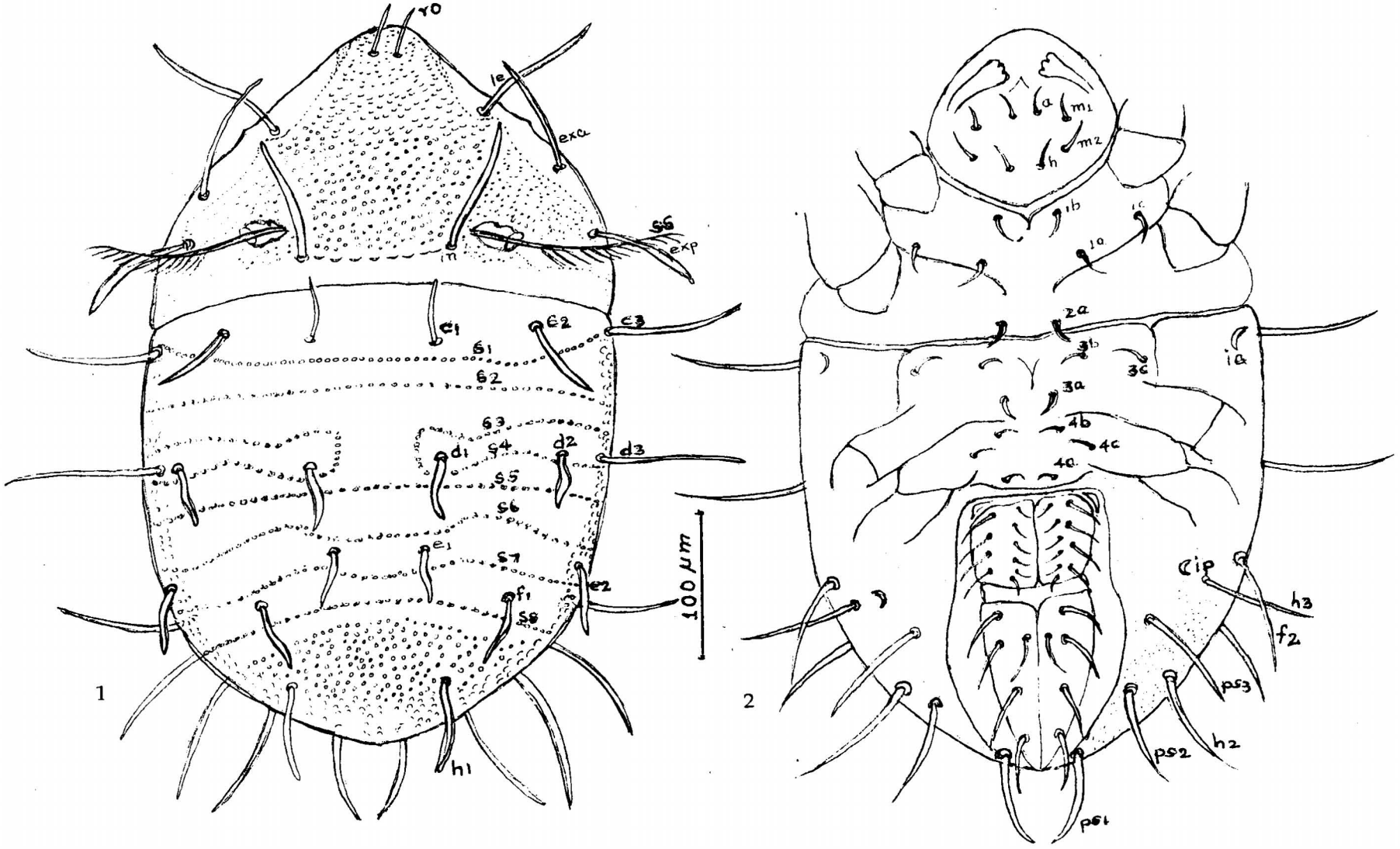
PLATE 32

***Haplacarus davisi* sp. nov.**

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 32


ro
le
exa
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exp
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e1
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e3
s1
s2
s3
d1
s4
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d3
s5
s6
e1
s7
f1
e2
s8
h1
100 µm
a
m1
m2
h
1b
1c
1a
2a
3b
3c
ia
3a
4b
4c
4a
cip
h3
f2
ps3
ps2
h2
ps1

1

2

PLATE 33

Haplacarus davisi SP. NOV.

Fig. 1 Bothridium and sensillus

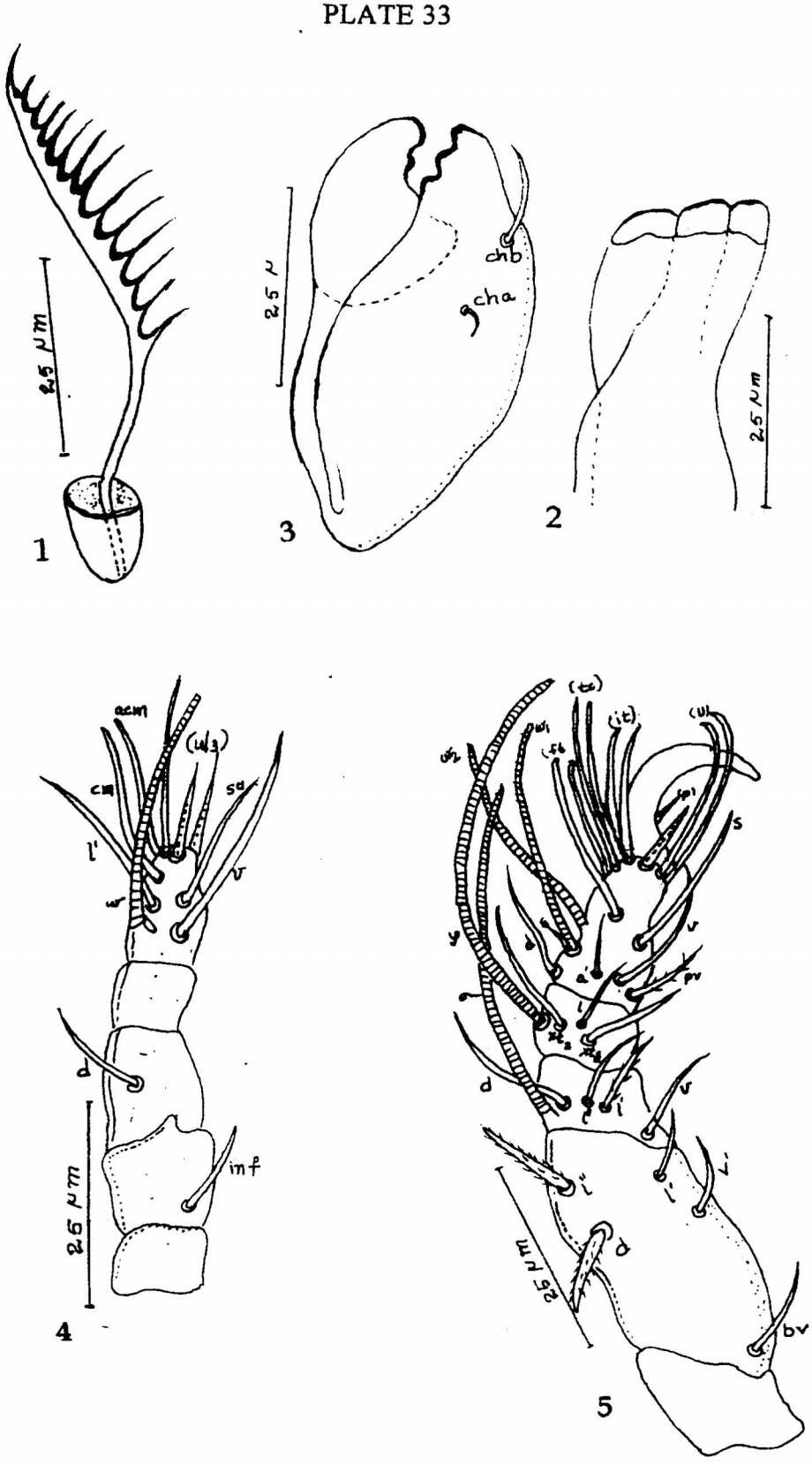
Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 33


25 µm
1
25 µ
chb
gcha
3
2
25 µm
acm
(u/g)
cm
sa
l'
v
d
inf
25 µm
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(te)
(it)
(u)
s
d
l'
v
l'
d
25 µm
bv
5

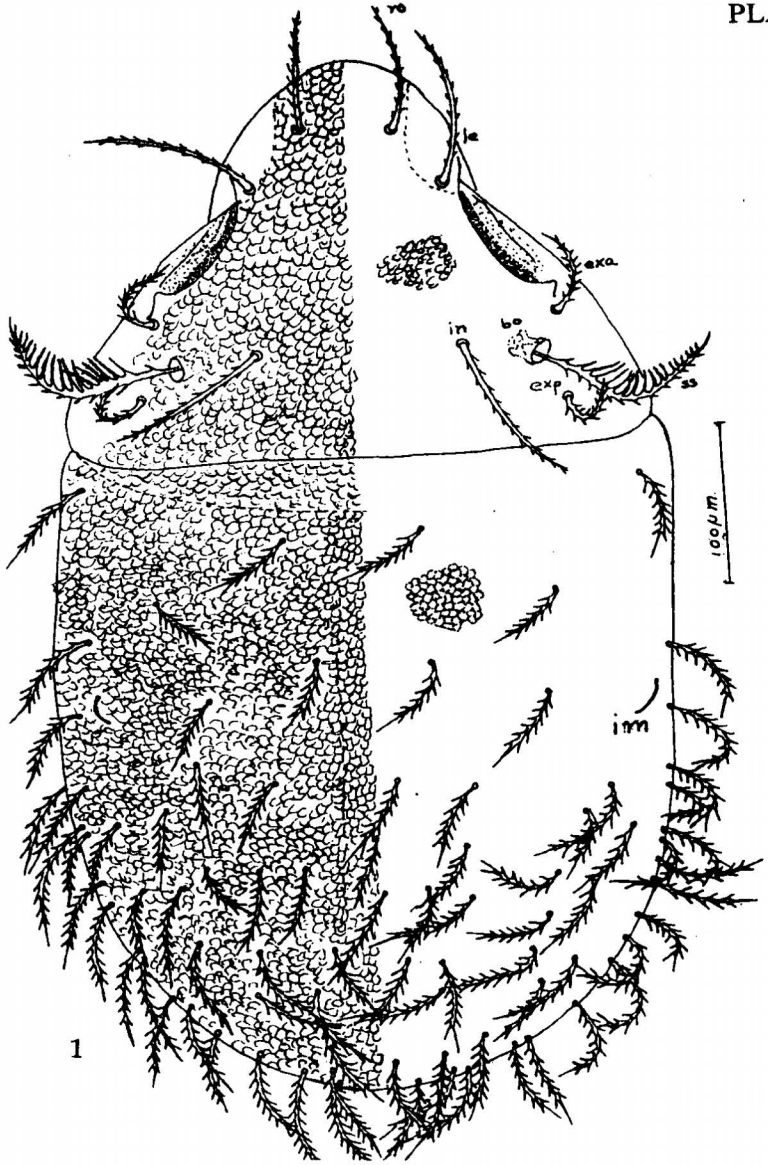
PLATE 34

Heptacarus indicus sp. nov.

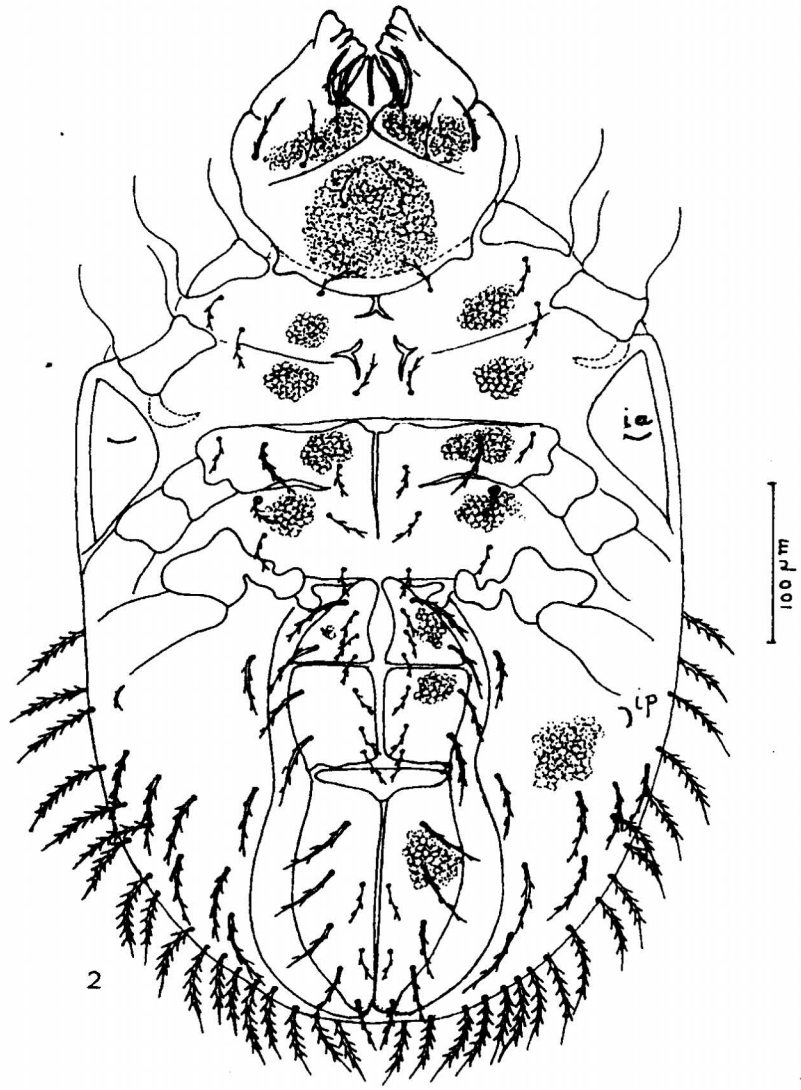
Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 34



1



2

PLATE 35

***Heptacarus indicus* sp. nov.**

Fig. 1 Lateral view

Fig. 2 Bothridium and sensillus

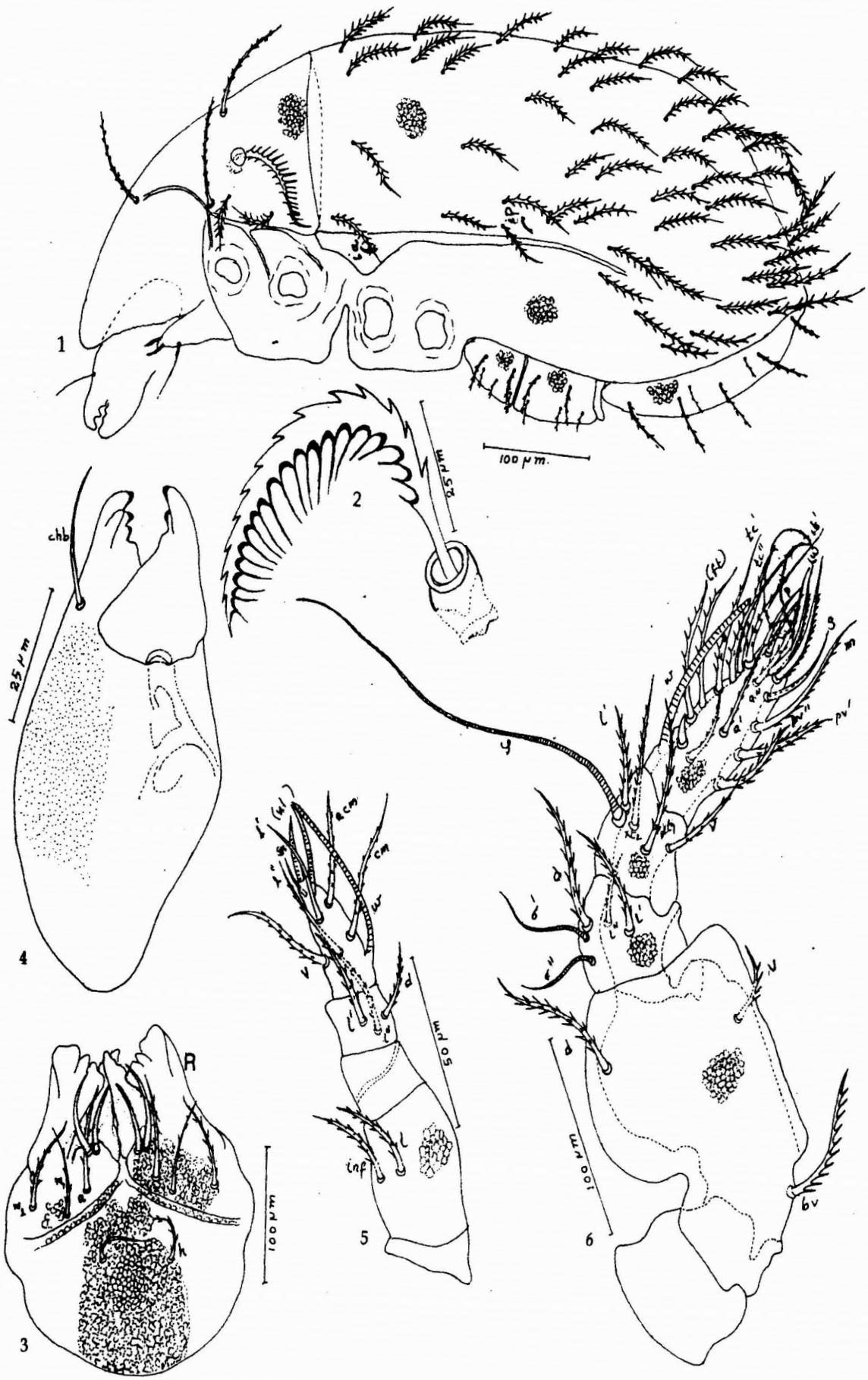
Fig. 3 Infracapitulum

Fig. 4 Chelicera

Fig. 5 Pedipalp

Fig. 6 Leg. I

PLATE 35



95

PLATE 36

Javacarus minutus sp. nov.

Fig. 1 Dorsal view

Fig. 2 Ventral view

Fig. 3 Bothridium and sensillus

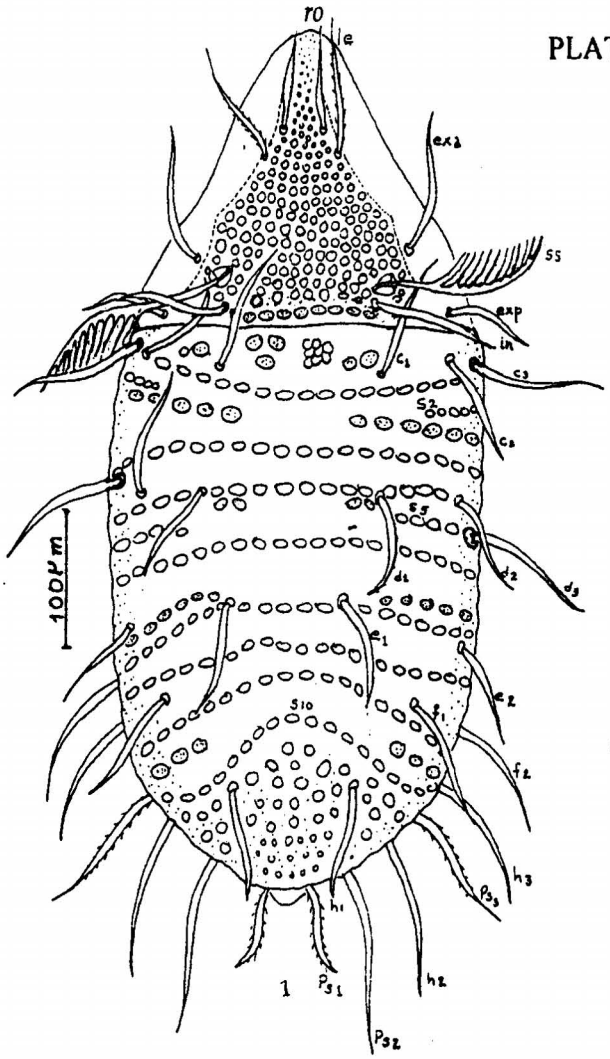
Fig. 4 Rutellum

Fig. 5 Chelicera

Fig. 6 Pedipalp

Fig. 7 Leg. I

PLATE 36


ro
e
ex2
ss
exp
in
c1
c2
c3
100µm
d1
d2
d3
e1
e2
f1
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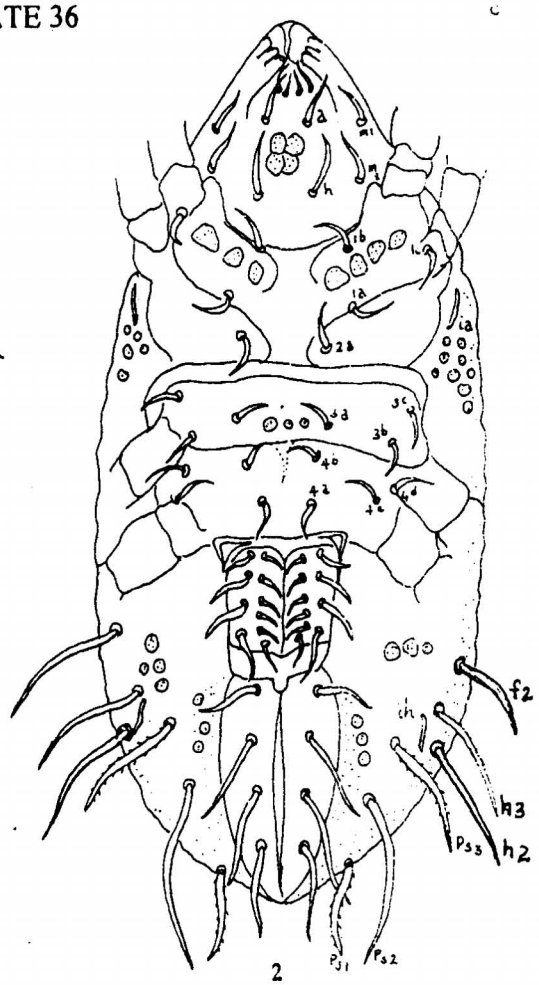
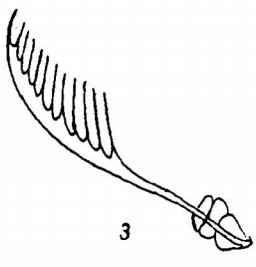
h1
h2
h3
Ps1
Ps2
Ps3
1


a
m1
m2
h
1b
1a
2a
3d
3c
3b
4c
4d
4b
4a
f2
ch
h3
Ps3
h2
Ps1
Ps2
2


3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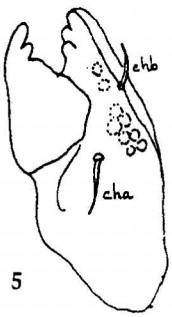
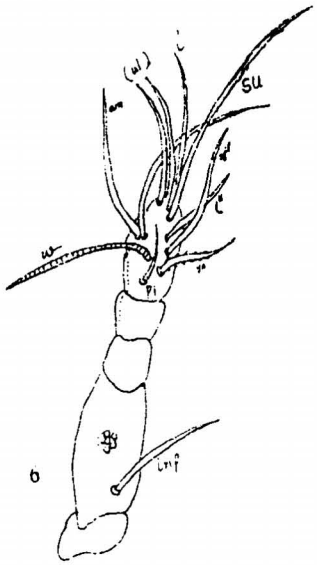

chb
cha
5


su
w
p1
6

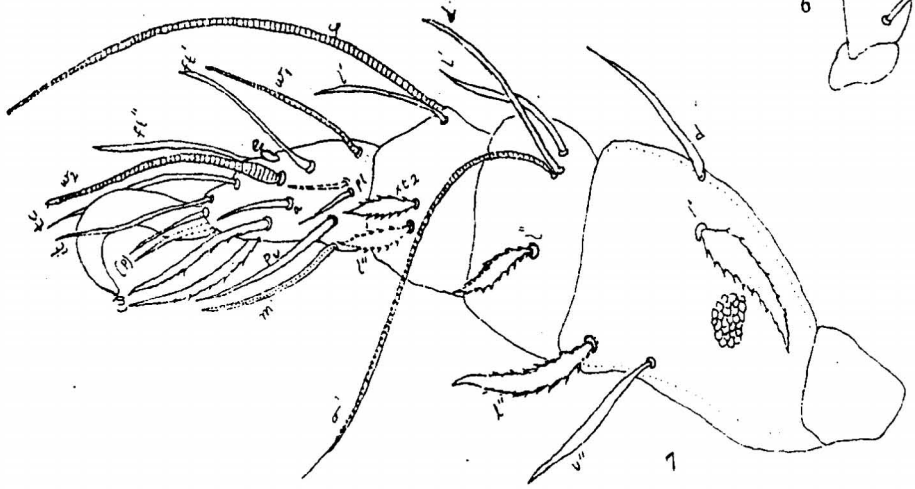

7

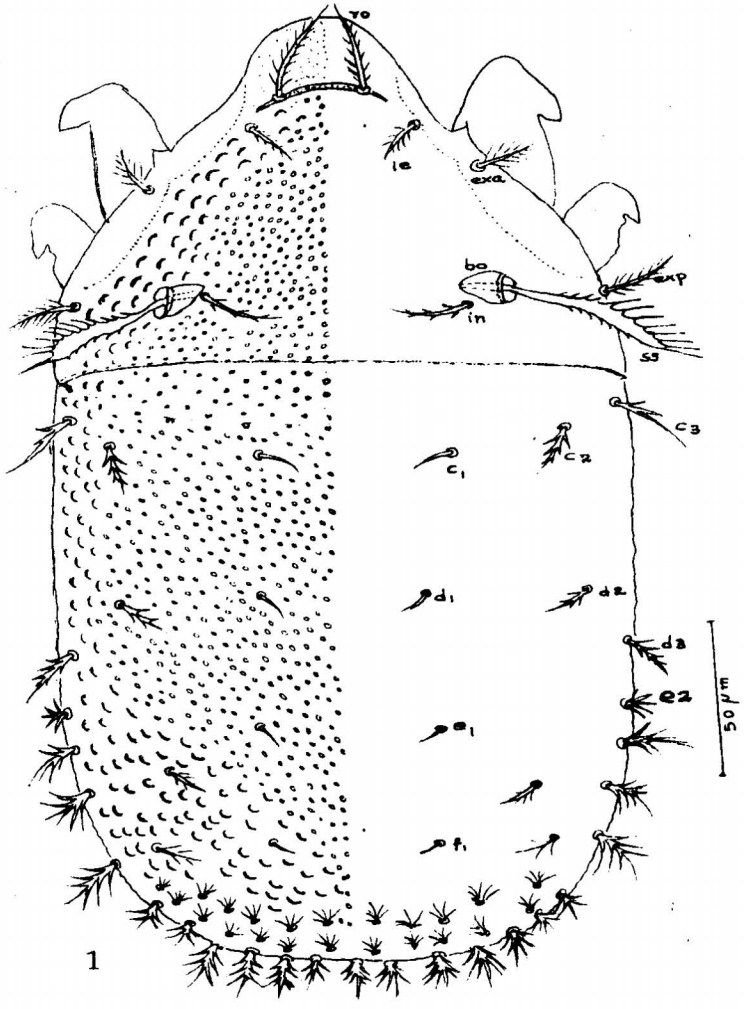
PLATE 37

Vepracarus arboriformes **sp. nov.**

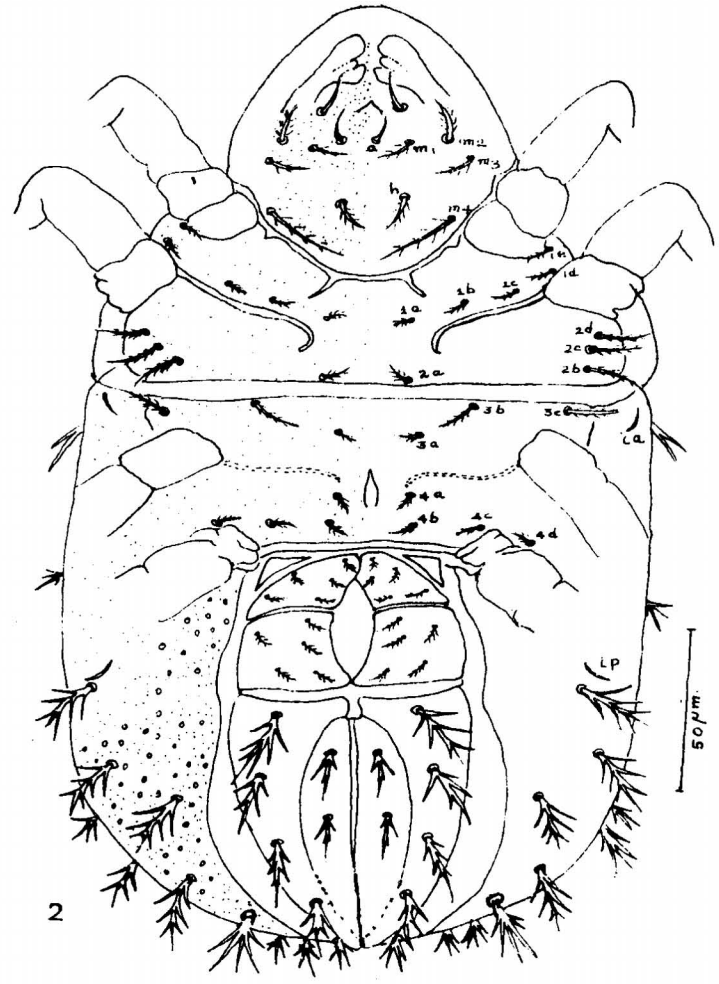
Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 37


vo
le
exa
ba
exp
in
ss
c3
c1
c2
d1
d2
d3
e2
e1
f1
50 µm

1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ca
4a
4b
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4d
LP
50 µm

2

PLATE 38

Vepracarus arboriformes sp. nov.

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 38

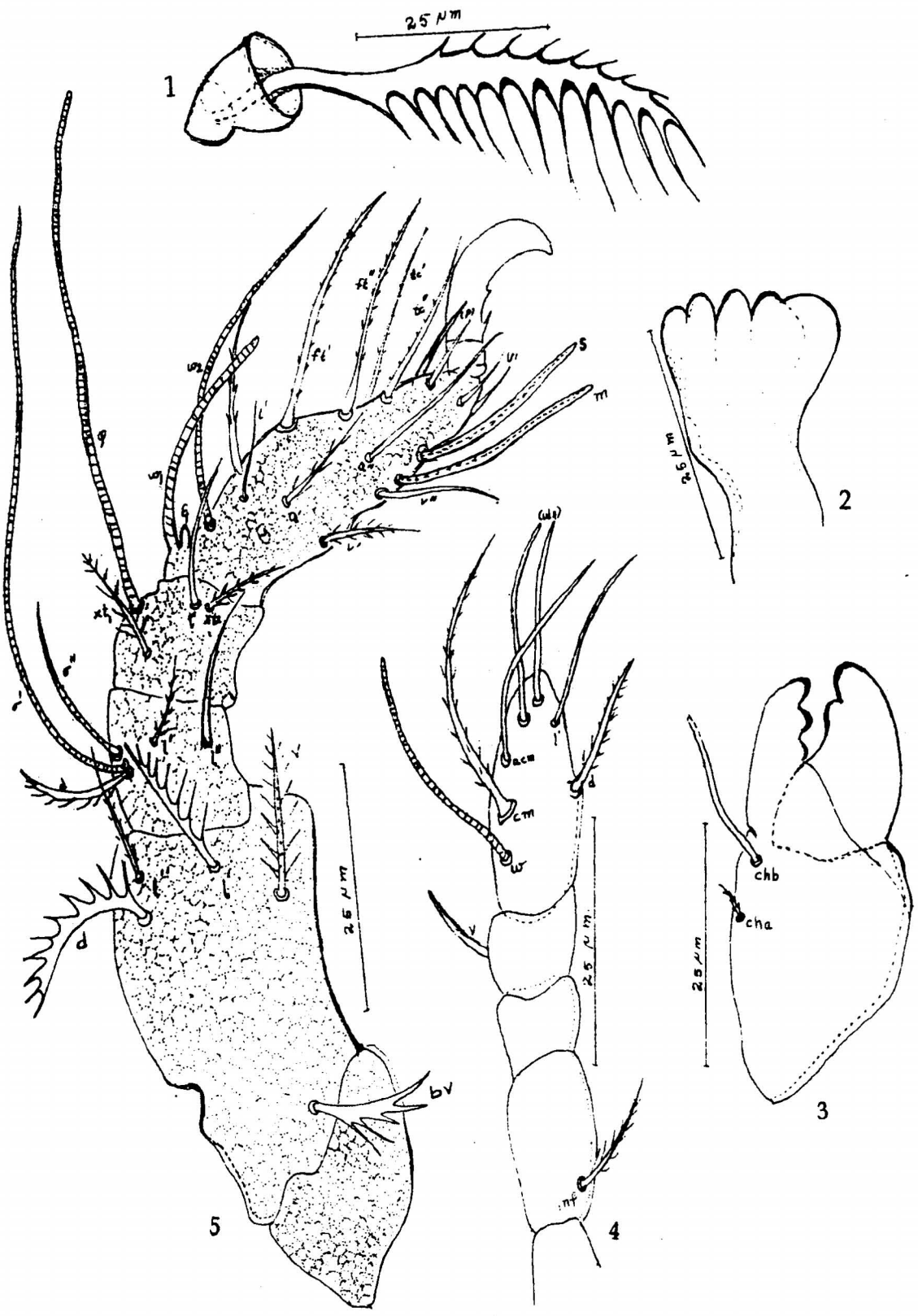


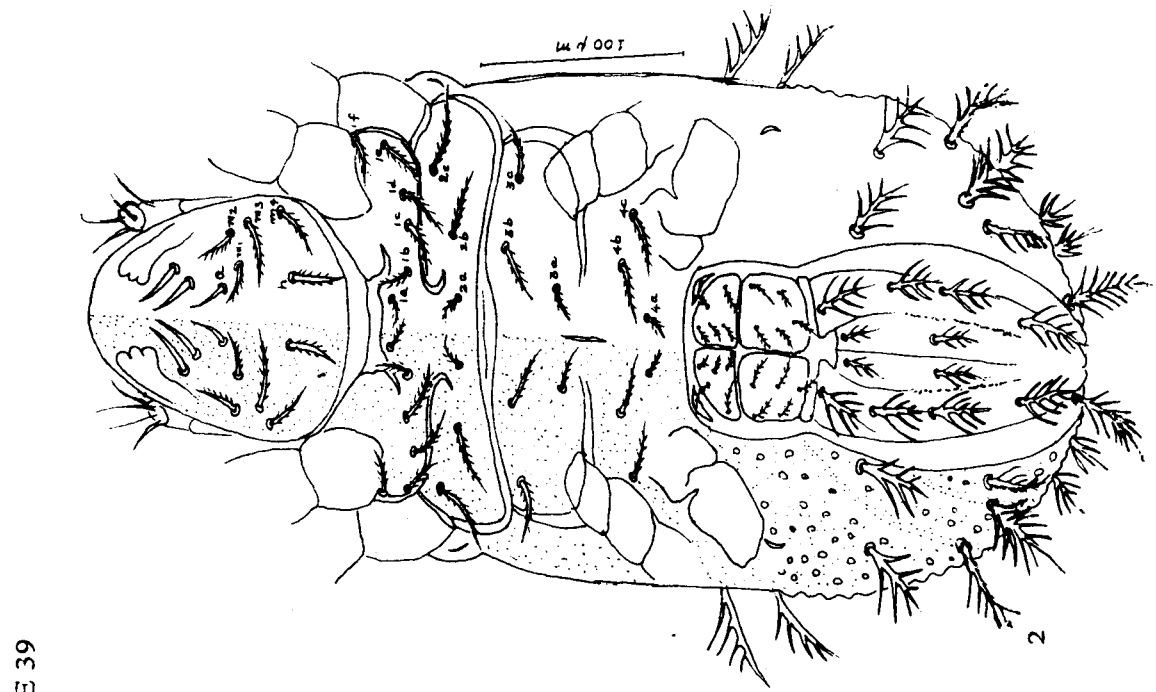
PLATE 39

Vepracarus ramaniae sp. nov.

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 39



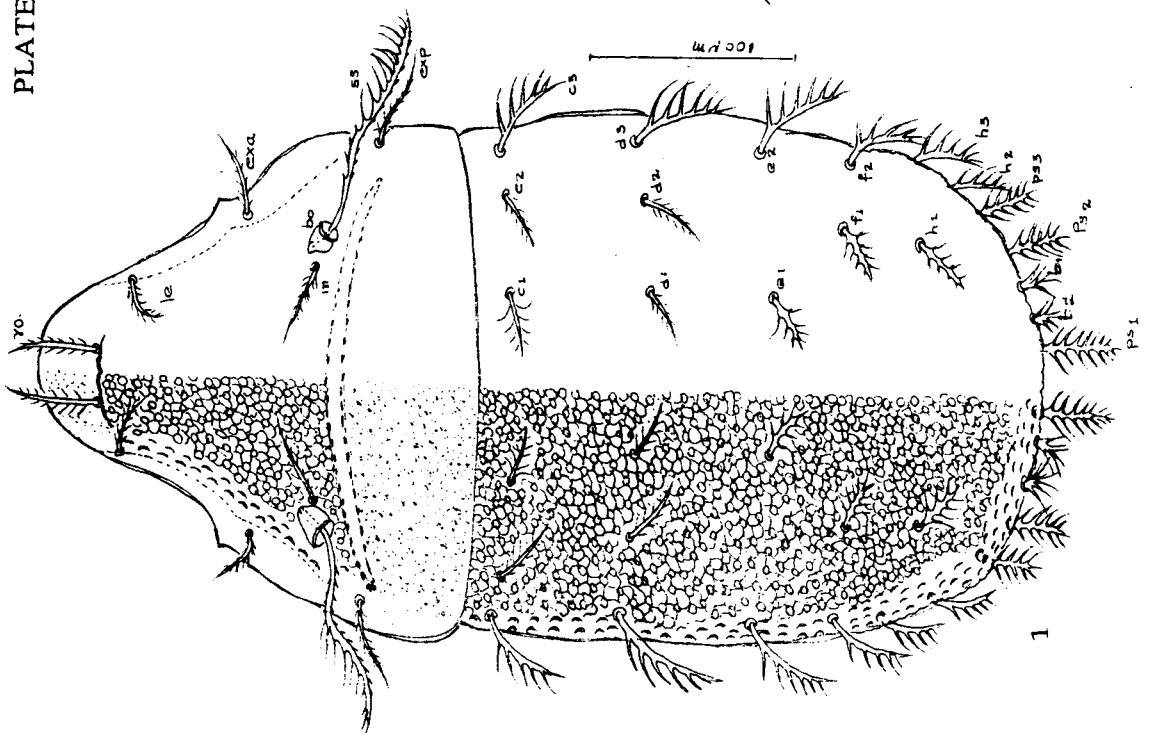


PLATE 40

Vepracarus ramaniae sp. nov.

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 40

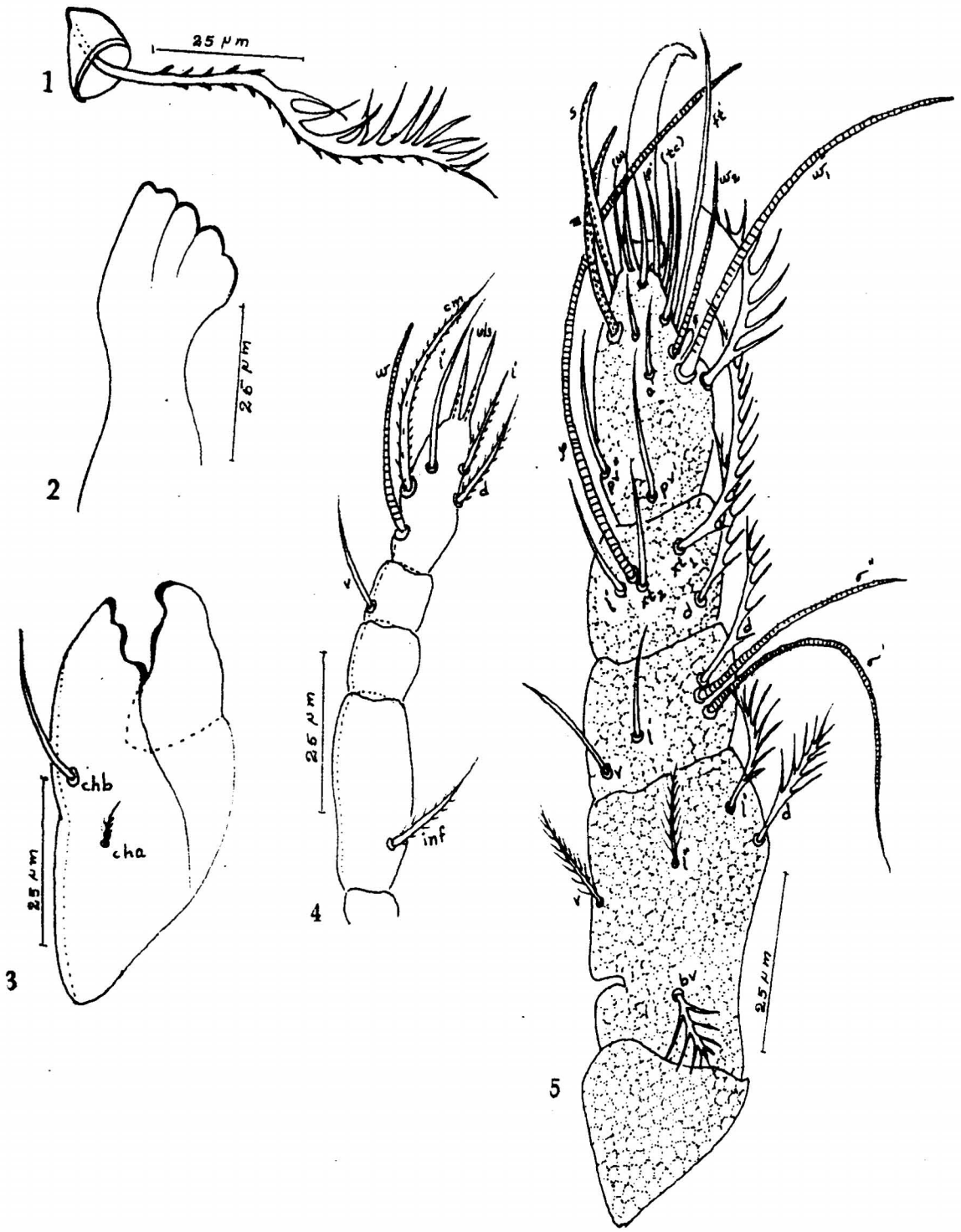


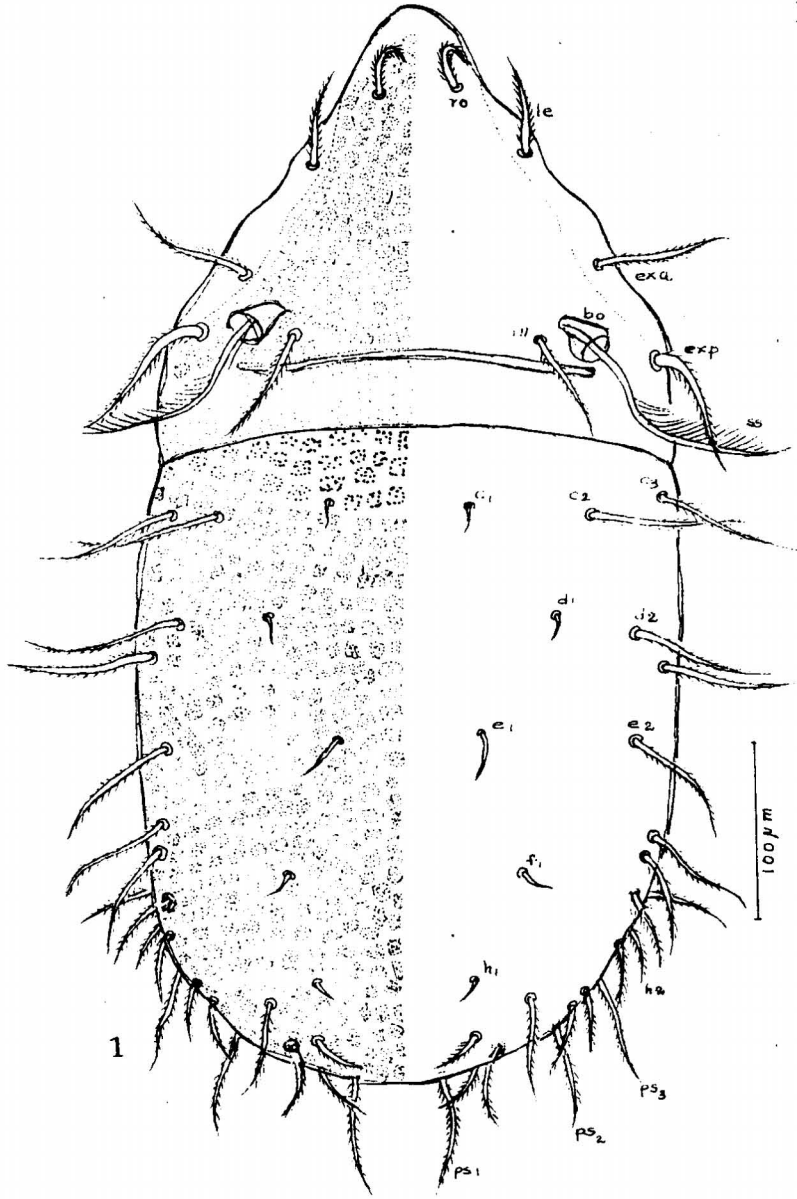
PLATE 41

***Papillacarus elongatus* sp. nov.**

Fig. 1 Dorsal view

Fig. 2 Ventral view

PLATE 41


ro
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ps3
100 µm

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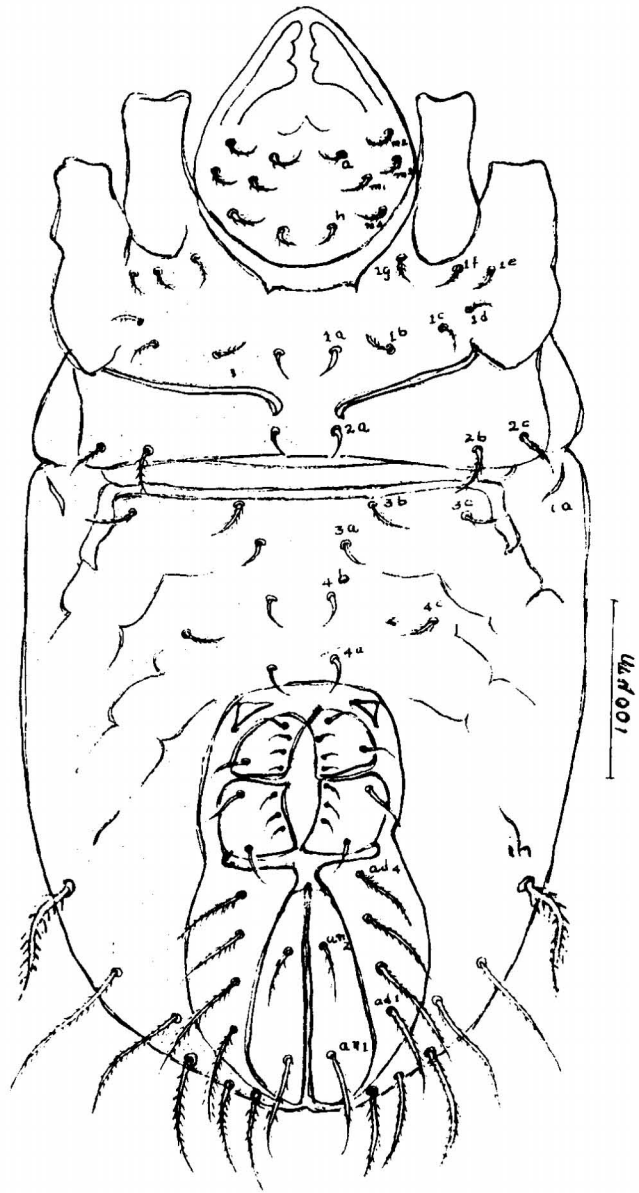
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3c
4a
4b
4c
ad4
um2
ad3
um1
100 µm

2

PLATE 42

Papillacarus elongatus sp. nov.

Fig. 1 Bothridium and sensillus

Fig. 2 Rutellum

Fig. 3 Chelicera

Fig. 4 Pedipalp

Fig. 5 Leg. I

PLATE 42

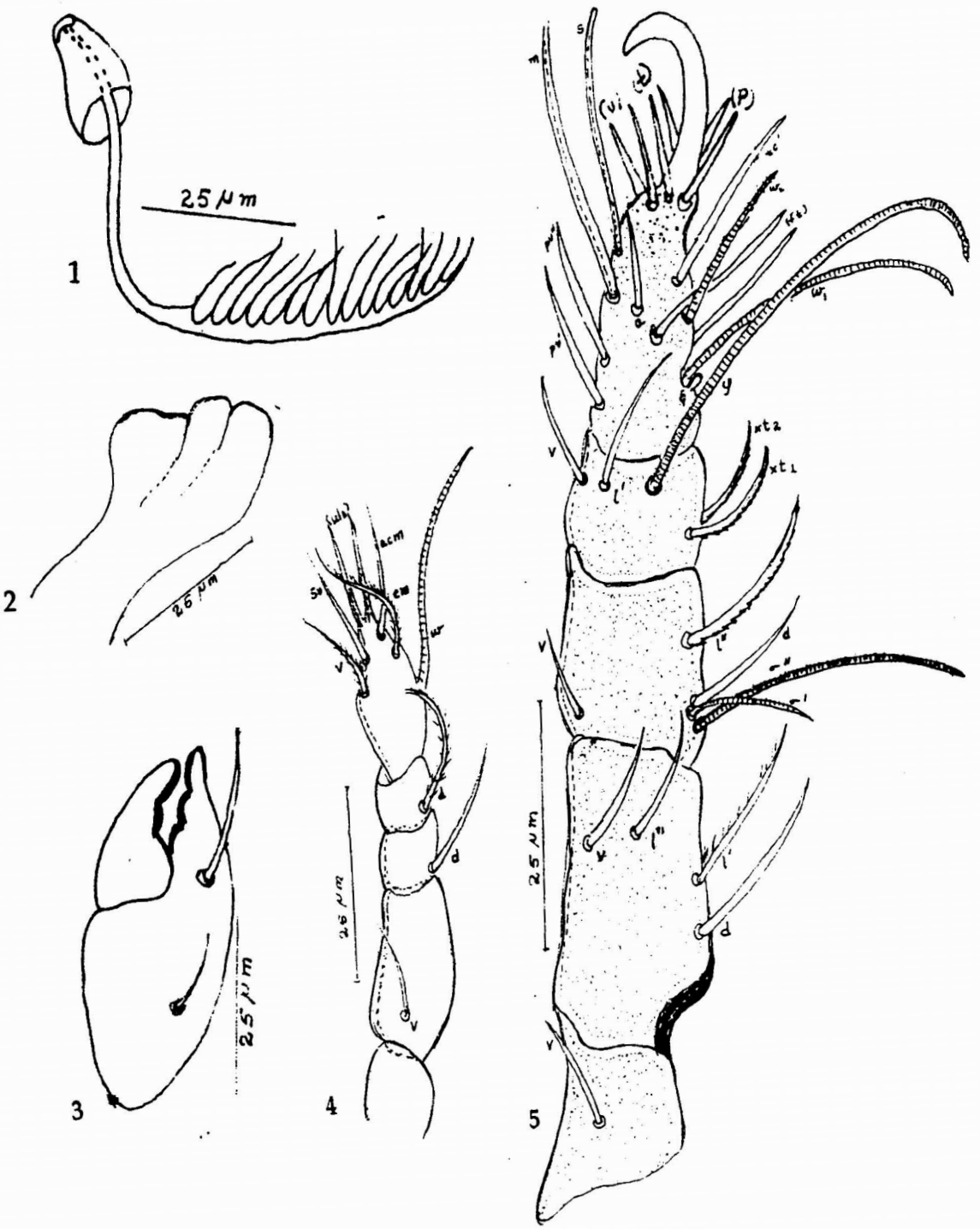


PLATE 43

Megalotocepheus glabrus sp. nov.

Fig. 1 Dorsal view

Fig. 2 Ventral view

Fig. 3 Bothridium and sensillus

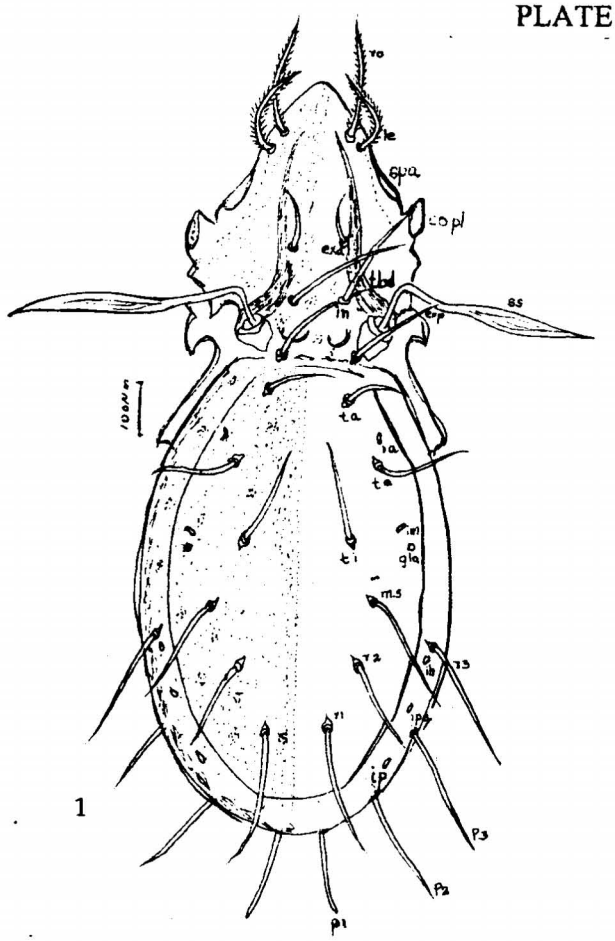
Fig. 4 Rutellum

Fig. 5 Chelicera

Fig. 6 Pedipalp

Fig. 7 Leg. I

PLATE 43



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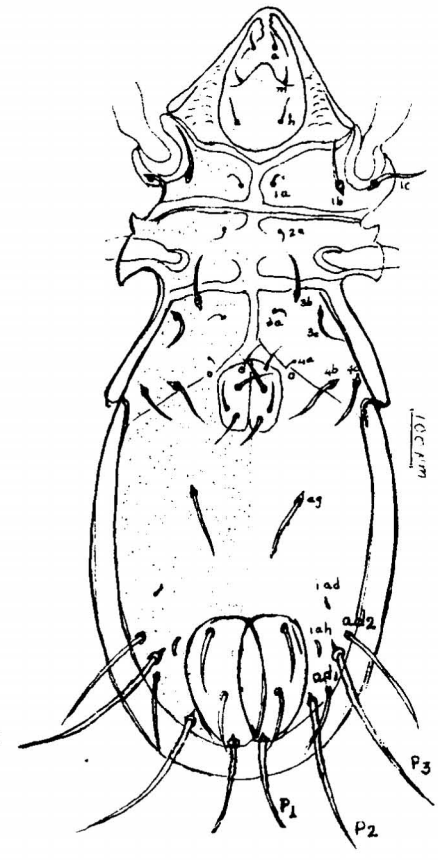

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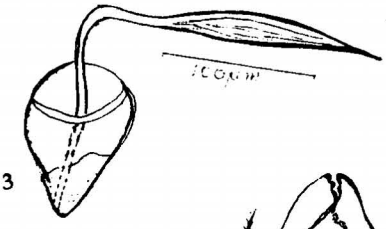

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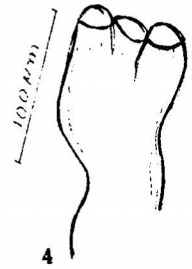

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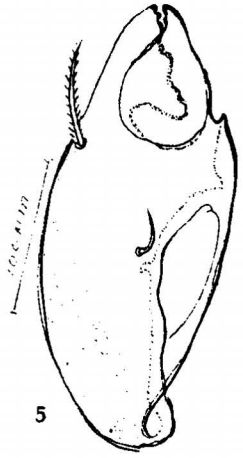

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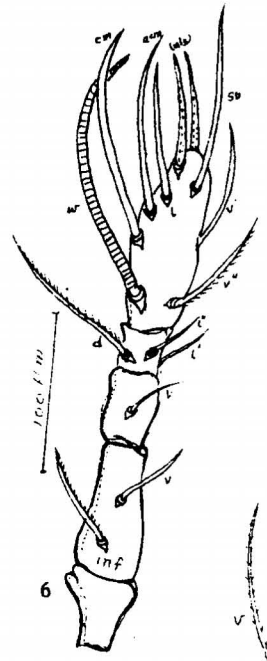

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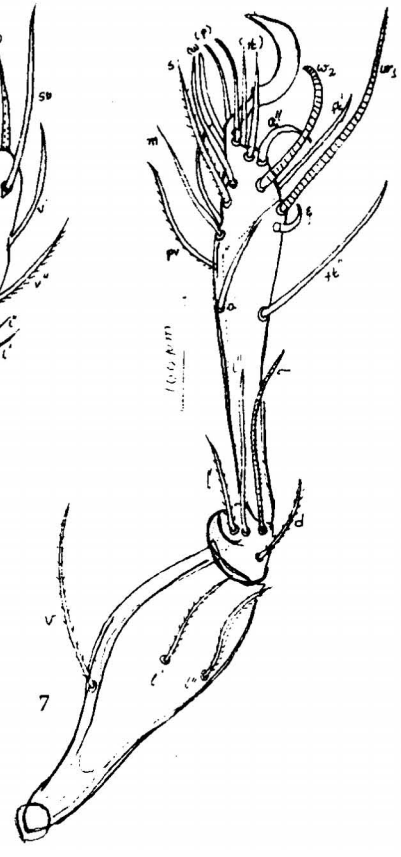


7

PART I
DISCUSSION

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

DISCUSSION

A qualitative and quantitative assessment of the oribatid mites present in vegetationally contrasting sites distributed in two districts of Kerala, viz., Malappuram and Calicut was made during the present study. The study was based on random sampling of oribatid mites from localities with varied floral constituents based on which these could be categorised as forest soil and litter accumulated regions, grass lands, agricultural fields, areas of monocultivation like Cashew, Acacia, Bamboo etc. and beach soil. Results of sampling disclosed a great deal of structural variation in the oribatid species diversity and density in all the localities surveyed, located within the premises of 30km. The variations observed in the oribatid diversity and density can be attributed to the topography of the soil, floral composition and the presence of organic litter. A large number of oribatid mites were collected of which only 58 species belonging to 21 genera, 11 families and nine superfamilies alone could be considered in the present study due to limitations of time. These 58 species consisted of both Oribatei Inferiores and Oribatei Superiores with representations from the most primitive to the most advanced members. This clearly indicates the presence of a rich and varied oribatid community that can be exploited for further studies.

The collection sites considered during the current study exhibited profound variation with respect to their vegetational characteristics. The floral composition was extremely diverse particularly in Calicut University Campus (UC) due to vastness of this site. This enabled further

categorisation of this site into Botanical Garden (BG), Secondary Forest (SF), Acacia Plantation (AP), Grass Land (GL), Cashew Plantation(CP), Bamboo Groves (BB), Paddy Field (PF) and Agricultural Garden (AG) represented respectively. Of these, BG, SF, AP, CP and BB were characterised by the presence of a thick layer of plant litter on the ground. GL was subjected to periodic cutting of grass and was devoid of plant litter. During cultivation period PF remained water logged while after harvest it was rather dry with remnants of the paddy stumps. AG also did not have any litter accumulation on the ground, as it was removed frequently.

The second study site at Kakkanchery (KS) possessed all qualities of a virgin forest with plenty of organic litter. The beach soil at Chaliyam (CB) which formed the third study site was characterised by the presence of drift wood accumulations in different stages of decay along with decaying root and stem of the plant *Calotropis gigantea* and molluscan shells. Drift wood accumulations occurred mainly during monsoon season, which was absent during other season. The fourth study site at Government Arts and Science College, Calicut (GC) though contained many large trees, did not contain much organic litter due to the regular cleaning practices. Despite of such vegetational peculiarities, all the sites except PF, AG and CB revealed the presence of oribatid mites as a major component of the soil fauna.

But the density and diversity of oribatid mites retrieved from each site exhibited marked variation. Species diversity decreased in the following order in the selected sites KS>BG>SF>BB>GC>CP>AP>GL>

CB>AG>PF while species density decreased in the order KS>SF>>BB>BG>CB>GC>CP>AP>GL>AG>PF. Thus the study showed that sites with high accumulation of organic litter supported a rich and varied oribatid population. The predominance of oribatid mites in forest floors and other areas of litter accumulation had been pointed out by earlier investigators (Hartenstein, 1962; Hayes, 1963; Wallwork, 1976; Ramani and Haq, 1991b; Hansen *et al.*, 1998; Kaneko and Salamanca, 1999; Jain *et al.*, 1999; Haq 2001, 2002).

The maximum number of oribatid mites consisting of 37 species was collected from site KS followed by BG and SF which yielded 33 and 32 species respectively. This general tendency of richness of species in these sites was found extending to the higher taxa like generic, familial and superfamilial levels also. Out of a total of 21 genera, 11 families and nine superfamlies collected in the present study, 17 genera, eight families and seven superfamilies were represented in site KS. Site BG yielded 16 genera, 10 families and nine superfamilies and SF had representation of 15 genera, nine families and eight superfamilies. This can be attributed to the soil profile of these sites, especially that of KS and SF with a thick upper litter layer of 20cm followed by decomposition layer of 5cm and humus layer of 15cm thickness. The availability of preferred food with rich and varied litter offered favourable conditions for the population build-up and abundance of oribatid species in these sites. In general, accumulation of litter leads to an increase in the organic content of soil. As a rule, the percentage of organic matter is considered as an index to the population density of soil organisms. This was evidenced in the

present study also which helped to recover an abundant oribatid population from these three sites. Many investigators have established a positive correlation between the organic matter of the soil and oribatid population density (Madge, 1965; Loots and Ryke, 1966; Fujikawa, 1970; Haq, 1994; Migliorini and Bernini, 1999; Gonzalez and Seastedt, 2000).

Sites AG and PF offered the minimum density and diversity of oribatid population. Twelve species belonging to seven genera, seven families and six superfamilies were recovered from AG while five species belonging to five genera, five families and four superfamilies were collected from PF. These two sites were characterised by the absence of litter leading to a decrease in the organic content of the soil. This substantiates the already established fact that oribatid population can thrive only in litter accumulated areas. This was especially true of paddy field which remained water logged during the period of cultivation and dry with litter only after harvest. Tian *et al.* (2000) had observed that abundance and diversity of oribatids in paddy fields was lower than that of typical forest ecosystem.

Sites AG and PF were agricultural lands used for cultivating vegetables and paddy respectively. Human activities in these agroecosystems ranged from physical intervention such as tilling and ploughing to the introduction of pesticides and fertilizers. Wallwork (1976) reported that repeated mechanical disturbances of the substratum causes unstable microclimatic conditions in the profile and also abrasive effects which can produce high mortality among soil animals. This was found true in the present work which showed the minimum

representation of oribatid mites in the above sites. The detrimental effect of mechanical disturbances on soil animals had been reported by earlier investigators (Sheals, 1956; Edwards and Lofty, 1969; Aleinikova and Utrobina, 1975; Ghilyarov; 1975, Shaddy and Butcher, 1977; Lebrun, 1978; Hulsmann and Wolters, 1998). Ito and Aoki (1999) and Badejo *et al.* (1999) suggested that oribatid population has been strongly suppressed by human intervention in the form of activities like cultivation. This was found true in the present study with respect to sites AG and PF.

Another important feature of the sites AG and PF was the regular application of pesticides for protecting the plants from pest attack. Pesticides bring about the destruction of not only the target animals but also others present in the habitat leading to a decline in the population of soil animals. This can be another reason for the recovery of minimum number of oribatid mites from these sites. Wallwork (1976) reported that in agricultural lands sprayed with pesticides, population recovery of animal is slow as in the case of cryptostigmatid mites with long life cycle.

Oribatid population of site CB was also poor consisting of 14 species belonging to six genera, six families and five superfamilies. This site was characterised by the absence of ground vegetation except for the scattered occurrence of the plant *C. gigantea*. Influence of ground vegetation on the species diversity of soil fauna becomes more clear when comparisons are made between this site and others like KS, BG and SF. The presence of ground vegetation increases the diversity of microhabitats available to soil animals (Wallwork, 1976). It encourages the establishment of populations of such mites as *Carabodes labyrinthicus,*

S. laevigatus, Achipteria coleoptrata and members of Lohmanniidae and Galumnidae which often move between litter and vegetation. These mites are rare or absent in locations where ground vegetation is poorly developed as was observed in this site. Added to this was the fact that CB was a beach where salinity conditions were high and constantly fluctuating. In this condition, only those forms which could withstand the fluctuation in salinity alone will be able to establish. This may be another reason for the decline in species diversity in this site. But interestingly, it was noted that population density of the species recovered was rather high in this site. Wallwork (1976) noted that there is no simple and direct relationship between the number of species present in a site and the number of individuals per species. It might be expected that in species poor sites, the number of individuals per species would be high, but this number would decrease if more species are added. This was found true in the current study as it was noted that the density of *H. indicus* and *A. (H.) chaliensis* recovered from this site was very high.

The oribatid population of site GC consisted of 22 species grouped under 12 genera, seven families and six superfamilies. Even though there were a large number of trees and plants, litter accumulation was prevented by regular cleaning and burning of leaves. This not only resulted in the absence of litter, but also led to the destruction of soil inhabitants including oribatid mites. This may be the reason for the low yield of oribatid population from this site. This observation is in confirmation with that of Badejo *et al.* (1999) who reported that density of

oribatid mites in a fallow that was burnt annually decreased over the year.

A scrunity of oribatid population retrieved from sites AP, CP and BB revealed a very interesting feature. The floral composition of these three sites consisted of a single plant species each. Viz., *Acacia auriculiformes, Anacardium occidentale* and *Bamboosa arundinacea* respectively. The ground had a thick accumulation of the corresponding plant litter in all the three sites. The density and diversity of oribatid population supported by these three sites exhibited great variation. Site AP was part of social forestry programme where large number of Acacia plants were present along the road side. 17 species of oribatid mites belonging to 10 genera, eight families and seven superfamilies were collected from this site. Site CP consisted of cashewnut plantation within the University Campus. This site yielded 20 species belonging to 11 genera, seven families and six superfamilies. Site BB was a bamboo grove. A total of 28 species belonging to 16 genera, nine families and seven superfamilies were collected from this site. On comparison with sites like BG, SF and KS the above density and diversity of oribatid population was low. These three sites with a single plant species can be considered as areas of monoculture. Wallwork (1976) reported that crop type may influence the distribution of those members of the soil fauna which are specifically associated with particular food plants. Monocutlure will eliminate those animal species which are associated with particular food plants. It is clear from the observations made in the present study that

only those oribatid mites which could utilise the respective plant litter alone survived in these habitats.

Of the above three sites, AP supported minimum number of oribatid species. Jain *et al.* (1999) observed a low mite density in the small leaf sized litter of Acacia as was evidenced in the present study also. But site BB which was also characterised by the presence of small leaves of Bamboo supported more oribatid species. The high percentage of phenolic content of Acacia leaves led to its slow decomposition (Jain *et al*, 1999). This in its turn resulted in a corresponding decrease in the oribatid population present.

A total of 16 species of oribatid mites belonging to nine genera, eight families and seven superfamilies were recovered from site GL. The site was characterised by high temperature and low humidity. Wallwork (1970) reported that open grass lands are subjected to constant fluctuations in temperature and relative humidity. Periodic cutting of the grass and grazing by herbivores did not allow luxuriant growth of grass. Moreover, during summer season grass dried up completely exposing the ground to direct sunlight. As such, grass lands are suitable for the existence of more hardy and metabolically active animal groups (Wallwork, 1970; Niemela and Baur, 1998). An analysis of the oribatid mites collected from this site showed that 11 out of the 16 species recovered belonged to Oribatei Superiores and only five to Oribatei Inferiores. Majority of these mites were highly sclerotised affording them protection against the impact of direct sunlight and desiccation. Members of Oppiidae. Scheloribatidae and Galumnidae were highly active and

could go deep into the soil layers. Members of Mesoplophoridae and Phthiracaridae could minimise water loss by withdrawing their body parts under the exoskeleton. The study thus showed the predominance of higher oribatids which are more hardy and metabolically active in grass land ecosystems. The study also brought to light the fact that lower oribatids in grass lands consisted of those forms with adaptations to resist water loss.

In the current work, out of the 58 species of oribatid mites identified 65.57% belonged to Oribatei Inferiores and 34.5% to Oribatei Superiores. The study also helped to erect 15 new species, four each from sites BG and KS, three from CB, two from SF and a single species each from AP, BB and GC. The new species, *J. minutus* obtained from BG was present in SF also. Thus 25.9% of the total oribatid population collected turned out to be new. Of this 93.3% belonged to Orbatei Inferiores and 6.7% to Oribatei Superiores. Further analysis showed that 33.3% of the new species were members of the lower oribatid family Phthiracaridae. and 60% Lohmanniidae. The superior oribatid family was represented by Otocepheidae. In short the new species erected belonged to three families coming under three superfamilies. While considering the numerical abundance of the various taxa, it was found that Lohmanniidae topped the list by accommodating eight genera and 25 species. This was followed by Phthiracaridae which yielded three genera and eight species. It is clear from the study that the sites selected accommodated a higher percentage of lower oribatids especially the Lohmanniidae and Phthiracaridae. These two groups of oribatid mites have been identified as potential agents in

biodegradation of organic litter of higher plant origin (Luxton, 1972, Shereef, 1976; Haq, 1982, 1984, 1987, 1992, 1994, 1996; Haq and Konikkara, 1988; Ramani and Haq 1990, 1991a and 2001). Most of the sites selected for collection of oribatid mites were characterised by the presence of large quantities of organic litter in the form of leaves and stem of various plants in different stages of decay. This provided an appropriate condition for the establishment of a large number of oribatid mites which could utilise this as food. Phthiracarid and lohmanniid mites which mainly depend on organic litter of higher plant origin hence could survive well in these sites. This explains the abundance of these two groups of mites in the areas surveyed.

Oribatid mites exhibit a wide variety of nutritional habits (Schuster, 1956; Hartensten, 1962; Woodring, 1963; Shereef, 1971; Luxton, 1972; Haq and Prabhoo, 1976; Haq, 1982, 1994, 1996a, Maraun *et al.*, 1998a). This imposes selection in pattern of their distribution, each species being better adapted to specific habitat which will offer their preferred food in plenty. In the present study, of the 58 species collected, 3 species viz., *A. longisetosus, O. kuhnelti* and *S. minuta* were present in all the sites studied. Wallwork (1976) reported that species of *Oppia* and *Scheloribates* viz., *O. nova* and *S. laevigatus* were present in a variety of soil conditions from heath land and forest mor to grass land mull. In the present study, the sites selected ranged from secondary forest ecosystem through grass land, agriculture and monoculture land to beach soil. All these sites were inhabited by the above three species. This shows the unique adaptability of these mites leading to a cosmopolitan or eurytypic distribution pattern.

More often, species are much more limited in their distribution, as was shown when faunal comparison between communities revealed variation in species composition (Wallwork, 1967). This was quite evident in the present study as 20 out of the 58 species of oribatid mites recovered were restricted to one or the other of the sites studied. These species can be regarded as extremely stenotypic in their distribution pattern. A similar observation was made by Evans *et al.* (1961) who reported that 26 out of the 67 species collected from seven forest soils were restricted to one or the other of these soils. The remaining 35 species collected in the present study from different sites occurred in different proportions. The study thus showed that the distribution pattern exhibited by oribatid mites is highly varied, ranging from extremely stenotypic to eurytypic condition. 51 7% of oribatid mites were found to be completely eurytypic, 60.34% moderately eurytypic and 34.48% extremely stenotypic.

The above categorisation of the distribution pattern was possible only with individual species. When the pattern exhibited by a higher taxonomic level like genus or family was taken, a totally different picture emerged. Observation made in the present study showed that the genus *Scheloribates* was the most prolific genus as its members could be collected in conspicuous numbers from the different study sites. The current study yielded seven species of this genus. As already mentioned, *S. minuta* was present in all the sites. *S. decarinatus, S. praeincisus* and *S. laevigatus* were present in all sites except site PF. *S. latipes* was absent in sites PF and GC. *S rectus* was found restricted to sites BG and KS while *S. cuyi* was unique to site KS. Thus it can be concluded that *S. minuta* is eurytypic, *S. cuyi*

stenotypic and the others range in between. Within the same genus, individual species often exhibit variation in their distribution. *Scheloribates* in general includes very active forms with a wide range of tolerance to various environmental factors. Their humidity requirements are minimum (Seniczak, 1980a) and are capable of surviving in a wide variety of habitats (Hartenstein, 1962; Krivolutsky, 1979; Haq and Ramani, 1987; Sheela and Haq, 1988; Badejo *et al.*, 1999; Park-Hong *et al*, 2000; Schuster *et al.*, 2000). The panphytophagous nature of these mites enable them to switch from one type of food to other depending on availability. Their food range is wide including fungi, higher plant parts and even substances of animal origin. These adaptive features explain the numerical abundance and species richness of this group of mites in the different study areas.

Of the two species of the genus *Oppia* collected during the present study, *O. kuhnelti* was present in all sites as already reported. The other member viz., *O. neerlandica* was absent only from sites PF and AG. This genus thus can be said to exhibit almost eurytypic pattern of distribution. These two species are small but very active and are known to undertake long migratory movements (Wallwork and Rodriguez, 1961; Wallwork, 1976; Winchester *et al.*, 1999). Tiny nature of their body would permit them to excavate the smallest pores available in the soil profile for hunting the food. The active nature would permit quick migration to newer habitats on exhaustion of food at a site. Such quick migratory habit would assist them in finding new and preferred food in one or the other habitat leading to their wide distribution.

A. longisetosus, the third eurytypic species was found to be panphytophagous (Haq and Prabhoo, 1976; Haq, 1982). Hence it will find no difficulty in adjusting with different habitats. This explains their occurrence in all the sites surveyed. Similarly, the higher oribatid species *X. seminudus* could be collected from all sites except sites CB and GC. The higher oribatid family Galumnidae was found to consist of seven species grouped under a single genus *Galumna*. Members of this genus also exhibited a wide range of distribution. This group of mites was reported to undertake vertical and horizontal migration (Tian *et al.*, 2000) and possess a high level of tolerance to changing environmental conditions. They exhibit arboreal habit (Haq, 1989, Ramani and Haq, 1991) and association with microbes (Haq, 1984; Haq and Konikkara, 1988). These adaptive trends helped them to explore new habitats where they get finally established as was observed in the present study.

The study revealed that the sites with large quantities of litter of higher plant origin supported a rich population of phthiracarid and lohmanniid mites. These two groups of mites were reported to be macrophytophages (Haq and Prabhoo, 1976; Behan and Hill, 1978; Haq, 1982, 1984, 1987, 1994, 1996; Haq and Konikkara, 1988) and could exist only in those areas where their preferred food was available. Most of these mites possessed comparatively bigger body, were lethargic and sluggish and often took refuge under or between leaves or in burrows bored into partly decomposed wood. This was evidenced in the case of the phthiracarid mite, *A.(H.) chaliensis* and the lohmanniid mite, *H. indicus* which bored into the root and wood of *C. gigantea*. Site PF was peculiar in

that, it did not harbour any of the lohmanniid or phthiracarid members while site AG supported two species of phthiracarid mites and a single species of lohmanniid mite. These two sites as was reported earlier, were devoid of leafy or woody elements as litter which formed the preferred food of these mites. Similarly, the only lohmanniid mite that could be retrieved from site CB was *H. indicus* which was a xylophagous species. This site was noted for the absence of leafy litter. Majority of lohmanniid mites are phyllphagous which restrict them to areas where leafy litter is available. The study thus showed the extreme dependence of phthiracarid and lohmanniid mites on organic litter of higher plant origin.

In the present study, an attempt was made to evaluate the population density of oribatid mites in relation to average monthly rainfall and temperature. Soil samples collected during monsoon period yielded the maximum number of oribatids while the summer collection yielded the minimum number. The total number of oribatid mites collected during the month of June when maximum rain of 568.2, 573.7, 564.9 and 572.1mm occurred, was 582, 120, 113 and 74 respectively from sites UC, KS, CB and GC. On the contrary, during March the collection was 102, 27, 10 and 18 respectively when minimum rain of 32, 29.7, 36.8 and 34.2mm occurred. A gradual increase in the population density was noted as the rainy season started, reaching a maximum in the peak of monsoon. Again a decline in the population density was observed as the monsoon receded, reaching the minimum in the peak of summer. This clearly indicated the influence of rainfall on the population build up of oribatid mites. Oribatid mites require optimum conditions of light,

temperature, and humidity to establish a good population density. Variations in these factors affect the density of population either positively or negatively depending upon the existing condition. This may lead to definite population fluctuation on a monthly, seasonal or annual basis (Hartenstein, 1962a; Madge, 1965; Mitchel and Parkinson, 1976; Clement and Haq, 1982; Reutimann, 1987; Fujikawa, 1988; Kaur *et al.*, 1998; Webb *et al.*, 1998). Oribatid mites generally are detritivorous organisms, feeding mainly on decomposing organic litter. Presence of moisture and rain accelerate the process of decay which make the food palatable for the mites. The abundance of their preferred food in the correct stage of decay enhances reproduction leading to an increase in population density. In the case of microphytophagous oribatid mites which subsist on bacteria and fungi, moisture enhances bacterial and fungal growth, providing them with ample food. This induces reproduction and subsequent population build up.

The data obtained on population was analysed statistically to establish the influence of rainfall on population density. Correlation coefficient between rainfall and population density in the four study sites viz., UC, KS, CB and GC was found to be 0.68, 0.66, 0.76 and 0.78. This established a significant positive correlation between population density of oribatid mites and rainfall. A similar observation was made by Trueba *et al.* (1999) who found the density of soil fauna including oribatid mites to be three times higher in rainy season. Gonzalez and Seastedt (2000) reported a higher density of total litter fauna and a higher taxonomic diversity in wet forest soils than in dry condition. Jain *et al.* (1999) found a

positive correlation of oribatid population with soil moisture who reported that litter was rich with mites predominantly in monsoon season. The present study thus established a definite positive correlation between population density of oribatid mites and rainfall.

The number of oribatid mites collected when the atmospheric temperature was a maximum of 37.5, 37.6, 37.4 and 37.3^{0}C respectively in sites UC. KS, CB and GC during the month of March was found to be very low as was given above. The minimum temperature of 29.2, 29, 29.3 and 29^{0}C was experienced in the month of June respectively in the four study sites and as already mentioned above, the number of mites collected during this month showed manifold increase over that of March. A similar observation was made by Dinesh *et al.* (1997) who reported a gradual increase in the number of oribatid mites from summer to autumn months and ranging between 675-2909/m^2 in a Eucalyptus forest floor and 364 to 789/m^2 in Acacia forest floor. On the contrary, Webb *et al.* (1998) found an 8-10% increase in soil dwelling oribatid mites by conducting soil warming experiments in tundra heath and polar semi-desert soil. The authors stated that this result was due to the fact that oribatid mite fauna of these soils was already well adapted to a wide temperature range and responded to short-term changes in the soil microclimate. The authors reported that there was no evidence to prove that persistent above-normal temperatures affected population growth rates. Unlike rainfall, temperature thus was found to have a negative influence on oribatid population density. The correlation coefficient for these two factors was found to be -0.90, -0.92, -0.90 and -0.87 with respect

to the four major study sites viz., UC, KS, CB and GC. The current study thus established that oribatid population density exhibited a strong negative correlation with temperature.

In nature, both these environmental factors exerts a combined effect on the oribatid population. It is a fact that during the rainy season, atmospheric temperature will be low and during the hot summer months, rainfall is scanty as was seen in the present study. It can be assumed that the onset of rain triggered reproductive activity leading to gradual population build up reaching a peak in August and a gradual decline reaching a minimum in April. Oribatid mites are known to undertake vertical migration as mentioned earlier. This may be a mechanism to escape from desiccation during the hot summer months when they will migrate to the deeper layers of soil where temperature conditions will be more favourable. This in turn leads to a lesser number of oribatid mites in upper layer of soil during summer leading to an apparent lower population density. These reactions of oribatid mites to variation in atmospheric temperature and rainfall, if analysed properly, can be utilised as bioindicators of soil conditions (Sheela and Haq, 1991; Smrz, 1994; Skubala, 1997; 1999; Enami *et al.*, 1999; Jain *et al.*, 1999). This warrants the urgency to initiate further studies to utilise these highly cryptic organisms in various fields of human interest like biodegradation of organic litter, enrichment of soil fertility and productivity and bioindication.

PART II
REVIEW OF LITERATURE

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

PART II
BIOLOGY OF ORIBATID MITES

A. FEEDING BIOLOGY

Chapter VII	– Review of literature
Chapter VIII	– Materials and methods
Chapter IX	– Observation
Chapter X	- Discussion

REVIEW OF LITERATURE

Biological activities of every organism require acquisition of the basic needs for survival in the existing conditions. Food is the primary requirement for immediate existence as well as reproductive potential of the species concerned. There have been several general and specific studies concerned with the food and feeding habits of oribaitd mites as well as a few useful reviews to summarise the knowledge. In this chapter, an attempt is made to consolidate the information available on the food and feeding habits of oribatid mites.

Michael (1884, 1888) was the pioneer in recognising the nutritional requirements of oribatid mites who successfully reared a few species like *Damaeus nitens, Notaspis bipilis* and *Cepheus palmicinctum* on lichen, decayed wood and cheese. Vitzthum (1923) confirmed the affinity of oribatid mites towards fungi and lower plant materials. Jacot (1936) cultured oribatid mites of *Pseudotritia sp.* on lichen. Forsslund (1939) while discussing the feeding habits of oribatid mites, reported that *Phthiracarus* which fed strictly on higher plant materials resorted to fungal diet under conditions of starvation. Food preference of oribatids was studied by Krull (1939) who reported that they fed on various food items like fungal hyphae and spores, debris, eggs of anoplocephaline tapeworms and cellular materials of decomposing grass. Feeding habits of *S. laevigatus* on pupae of parasitic Hymenoptera were observed by Vitzthum (1943).

Grandjean (1950) cultured oribatid mites like *Nothrus palustris, N. silvestris, Nanhermannia nana, Camisia segnis* and *Platynothrus peltifer* on lichen. Riha (1951) reported that *Pelops sp.* cut out pieces of epidermis from dry, undecomposed leaves with its chelicera while feeding. Sengbusch (1954) cultured three species of *Galumna* viz., *G. nervosa, G. elimatus* and *G. longipluma* on moss and algae. Murphy (1955) studied the feeding preference of *Steganacarus magnus*. Studies conducted by Rhode (1955) confirmed moss as the preferred food of *Euphthiracarus flavum, Pseudotritia sp.* and *Oribotritia sp.* Pauly (1956) reported that algae and fungi were the most suitable food for culturing three species of *Belba viz., B. geniculosa, B. clavipes* and *B. boreus*. Schuster's (1956) observations on oribatid feeding paved the way for the formulation of a nomenclatural framework to describe the feeding patterns of oribatid mites as a whole. He grouped these mites into three categories viz., macrophytopages (feeding on higher plants), microphytopahges (feeding on microflora) and non-specialists (feeding on both the above mentioned food materials). Wallwork (1957) reported the burrowing habit of the adults and immatures of some oribatids on the bark and hard wood of fallen twigs.

Grandjean (1957) studied the structure of mouth parts of oribatid mites in relation to feeding activity. He observed that rutellum is a modified form of infracapitular seta which facilitates feeding. Wallwork (1958) studied the feeding behaviour of several species of soil inhabiting oribatids in relation to the selective decomposition of litter. According to him, the factors affecting food preferences appeared to be particle size,

structure of mouth parts, nature of digestive system, stage of chemical decay of food and moisture content of food. Sengbusch (1958) reported that the algal species *Protococcus* and moss served as excellent food items for culturing a variety of oribatid mites.

An interesting observation was made by Graves (1960) who reported that *Galumna sp.* could feed on live larvae of flies. Fuhrer (1961) studied the association between bacteria and mites. Engelmann (1961) suggested that mites could be used for the control of fungi and bacteria. Macfadyen (1961) pointed out that soil oribatid mites could cause rapid re-infection of soil samples by transporting micro-organisms on and in their body. *Humerobates rostrolamellatus* was identified as a pest of split cherries by Evans *et al.,* (1961). They also reported that *Perlohmannia dissimilis* was capable of causing damage to tulips and potatoes. Bhattacharya (1962) offered a variety of food materials to six species of mites he studied and found that several species were omnivorous.

Feeding specifications of different species of oribatid mites were worked out by Hartenstein (1962 to 1962 f) through a series of papers. The author (1962) recognized three types of feeders among oribatid mites viz., primarily wood and leaf feeders, primarily fungivores, but would feed on wood and leaf tissue and strictly fungivores. In the same year (1962 a) he found *Belba kingi* feeding upon fungi and breaking down organic residues making nutrients available to the plants. By offering different types of fungi to *Metabelba montana* and *Eremobelba nervosa* he showed the preference of these mites to certain specific types of fungi (1962 b). The same author (1962 c) reported that *Ceratozetes gracilis* lived

in the litter layer of soil and fed on fungi. He (1962 d) showed that *Platynothrus peltifer* derived its sustenance from fungi and other micro-organisms. *Protoribates lophotrichus* was found to feed specifically upon decaying parenchymatous leaf tissues rich in living micro-organisms (1962 e). The author (1962 f) found that immature stages of *Steganacarus diaphanum* fed specifically upon the decaying sclerenchyma and endoderm of conifer needles.

Hayes (1963) showed the ability of three species of phthiracarid mites to feed on fresh leaves of higher plants, thereby enhancing biodegradation of fresh plant parts. According to Woodring (1963), orbatids normally feed on partially or completely decomposed plant parts. Gasdorf and Goodnight (1963) reported a proportional increase in lignin and decrease in cellulose in the faeces of *Peloribates* sp. and *Hermannia* sp. of oribatids. Madge (1965) investigated leaf fall and litter disappearance in a tropical forest at Ihadam, Nigeria. He concluded that litter disappeared mainly during the wet season owing largely to the activity of mites and Collembola. Wallwork (1965) detected the leaf boring nature of immatures of *Orthogalumna terebrantis* on the leaf tissue of the aquatic weed, *Eichhornia crassipes*. The extent of damage caused by this mite on the host plant was studied by Silveria Guido (1965). Woodring (1965) described the preferential feeding of *Rostrozetes flavus* on the sheaths of decomposed roots.

Wauthy *et al.*, (1966) expressed that members belonging to the same species develop enzymatic polymorphism due to nutritional and environmental adaptation. This observation was based on investigation

carried out by the authors using two subspecies of the oribatid mite, *Quadroppia quadricarinata*. Luxton (1966) confirmed the nature of feeding and behavioural aspects of oribatid mites collected from salt marsh soils. The zoophagous nature of *Pergalumna omniphagus* was established by Rockett and Woodring (1966) by noticing its predatory habit on nematodes. The direct and indirect effects of soil oribatids in soil formation, plant productivity and litter decomposition by their vertical translocation of organic matter to deeper soils was studied by Wallwork (1967). He added that many species of oribatids had a tendency to feed on the faeces of other animals. Kowal (1969) measured feeding rate of *Cultroribula juncta* on natural pine-moors by estimating Ca_{45} accumulation.

Woolley (1970) indicated that members of the oribatid families, Oribatulidae and Oppiidae could be reared nearly on any food substance while Liacaridae, Tenuialidae and Xenillidae were food specific. Shereef (1970) assessed the feeding preference of oribatids by providing them two different species of fungi viz., *Penicillium* sp. and *Aspergillus* sp. Mignolet (1971) also estimated feeding preference of oribatid mites. He provided various types of fungal diet to these mites and recorded their response to individual species of fungus. The ability of some oribatid mites to digest cellulose and other plant polysaccharides like pectin, chitin etc was studied by Spain and Luxton (1971). Kowal and Crossley (1971) worked out the influence of temperature on ingestion and egestion rates in oribatids. Bernini (1971) with the help of electron microscope studied the ultra structural details of the alimentary canal of four species

of oribatid mites viz., *S. laevigatus, S. anomalus, Xenillus tigeoribates* and *Phthiracarus* sp. He studied in detail the histology of different regions of the gut. Zinkler (1971) analysed carbohydrases present in litter dwelling oribatids. He found that macrophytophagous and omnivorous oribatids were able to attack plant structural polysaccharides by carboxy methyl cellulase, xylanase and pectinase which were recognised as very important in primary decomposition. The same author (1972) reported that microphytic feeders could digest only intracellular compounds of algae, fungal mycelia and bacteria with the help of maltase and amylase.

Schuster's (1956) classification of oribatid mites based on feeding habits was reviewed by Luxton (1972). He enlarged the classification substituting the term panphytophages for non specialised feeders. He added further terms like(4) zoophages (feeding on living animal material) (5) necrophages (feeding on carrion) and (6) coprophages (feeding on faecal material). Webb and Elmes (1972) measured the rates of ingestion, egestion and respiration in newly moulted and mature males and females of the soil dwelling oribatid species, *S. magnus*. He further utilised the data to derive an energy budget. Tadros (1973) found that oribatid species of the families Oribatulidae and Oppiidae could be reared on more than one food stuff. He noticed that species belonging to the family Epilohmanniidae accepted only a limited number of food items. Species belonging to the family Lohmanniidae refused to nourish on any of the limited substances offered. Pande and Berthet (1973) studied food habits of oribatids inhabiting a Black Pine forest and concluded that food habits of immatures varied from that of the adults.

Dinsdale (1974) studied the morphology of the gnathosoma of a phthiracarid mite with the help of electron micrograph to elucidate its functional significance. The same author (1974a) investigated the enzymatic activity in the gut of phthiracarid mites to determine the mechanism of digestion. Harding and Stuttard (1974) reviewed the various roles played by collembolans and mites in the decomposition of plant litter. Narsapur (1974) fed *S. laevigatus* and *S. fimbriatus* with the eggs of *Avitellina lahorea* to study the development of cysticercoids in the body cavity of these mites. Luxton (1975) provided information on oribatid biomass based on colorimetric analysis and discussed it in terms of life histories and metabolic rates. Del Fosse *et al.,* (1975) studied feeding mechanism of waterhyacinth mite *O.terebrantis.* Through radioisotope method, they estimated the relative feeding of the mites on injured and uninjured leaves of the host plant. Their experiments showed that there was no difference in the rate of feeding on injured and uninjured leaves. Feeding habit of the above mite was studied by Cordo and De Loach (1975) and the authors recommended this species as an effective biological control agent for the eradication of waterhyacinth.

Haq (1976) conducted feeding experiments on twenty species of oribatid mites and concluded that the wide range distribution of panphytophagous species reflect their ability to digest different varieties of food available in their habitat. Haq and Prabhoo (1976) assigned ten species of oribatid mites to the category of panphytophages by employing suitable staining procedures. The authors observed that no two species agreed perfectly with each other in their feeding habits.

Mitchel and Parkinson (1976) demonstrated that laboratory feeding studies were a poor indication of feeding type. They also suggested that there was no direct relationship between the amount of mite feeding and reproductive success. Shereef (1976a) reared two species of lohmanniid mites on wood and dry leaves. Stefaniak and Seniczak (1976) carried out microbiological studies on adults and immatures of the polyphagous species *Achipteria coleoptrata*. Their studies revealed that microflora of alimentary canal depend on the type of food eaten. The gut microflora of immatures were more abundant, active and varied compared to the adults. Tadros (1976) found that arachnids played the maximum role in the process of litter decomposition where the contribution of oribatid mites was 'quite significant. Marcuzzi and Lafisca (1976) studied the presence of carbohydrases in several litter dwelling oribatids. The authors showed that oribatids had a greater digestive ability and each species possessed several enzymes.

Behan and Hill (1978) described feeding habits of twenty five species of oribatid mites. They analysed the direct and indirect effects of oribatid mites on decomposition process. The authors added that 50 percent of oribatids adopted 'eurytypic' feeding habits which proved advantageous for their survival. A detailed description about the activities of soil mites in various ecosystems particularly soil fertility, biogeochemical cycles, humification, bio-indication and in the detection of residual concentration of pesticides was given by Lebrun (1978). Reddy *et al.*, (1978) studied the influence of food on the developmental period of *G.flabellifera*. Seniczak (1978) reported that alimentary canal

microflora of immatures of *A. coleoptrata* were more active and possessed the ability to digest cellulose, lignin, chitin and pectin. Seniczak and Stefaniak (1978) reported that microflora of alimentary tract in *O. nitens* depended on quality of food taken. They also observed that the alimentary tract microflora was clearly distinct from that of the feeding habitat.

Haq (1979) observed that adults of *G. flabellifera orientalis* fed on decomposed leaves of *Artocarpus* sp. while larvae preferred the fungus. *Alternaria* sp. Schatz (1979) studied the nutritional biology of fourteen oribatid species. He divided these mites into three different feeding groups viz., micro, macro and panphytophages. The author suggested that there was neither seasonal differences in the feeding habits nor between instars. A possible correlation between application of manures and fertilizers and abundance of species composition of soil inhabiting mites was worked out by Haarlov (1979). Purrini *et al.,* (1979) reported the occurrence of parasitic protozoa in the alimentary tract of oribatid mites. While studying the evolution of phytopagous mites, Krantz and Lindquist (1979) speculated that edaphic saprophagous and mycophagous mites become pre adapted to phytophagy due to the lack of major ecological barriers. Luxton (1979) presented a detailed review of the nutritional biology of oribatid mites. He compiled the data on the rate of food processed by these mites.

Young and Block (1980) studied the rate of respiration and metabolism in an oribatid mite, *Alaskozetes antarcticus* when fed on lichen species, *Xanthoria canclelaria.* Their studies revealed that mites selected

their food on the basis of nutritional value. Rockett (1980) studied nematophagy in *Nothrus* sp., *Fuscozetes* sp., *Ceratozetes* sp. and *Pergalumna* sp. The author reported that this feeding habit occurred more frequently among superior oribatids. Andre and Voegtlin (1981) studied the biology of *Camisia carolli*. The authors reported this mite as a mycophagous species which fed on pioneer fungi colonising young twigs of Douglas fir. Purrini (1981) reported the presence of endozoic amoebae in the gut of oribatid mites. Vikram Reddy (1981) illustrated the various indispensable functions performed by different groups of acari. The author stressed the importance of mites in nutrient cycling, energy flow, bioindication, decomposition and soil aeration.

Haq (1982) grouped ten species of oribatid mites from litter sample into three major feeding categories, viz., microphytophages, macrophytophages and panphytophages. He also made an assessment of carbohydrases present in the gut of these species which enabled the mites in degrading plant materials. Clement and Haq (1982) reported the fungus *Pestalotia* sp. as the preferred food of the oribatid species, *P. malabarica* and found that this food item accelerated the rate of spermatophore deposition and egg laying by this mite. Ramani and Haq (1982) studied the phytophagous nature of *P. bengalensis* on the tuber crop, *D. alata*. Behan and Hill (1983) determined the feeding habits of sixteen species of oribatids and reported that fifteen out of the sixteen species were panphytophages and acted as regulators in the process of mobilisation of minerals, dissemination of fungal spores and as temporary store house of nutrients. Hagan and Norton (1983) explored

the impact of human disturbance of the habitat on the richness of oribatid fauna. The authors reported that sites with highest calcium content had higher species richness.

Gjelstrup and Sochting (1984) studied the dominant species of oribatid mites inhabiting lichen and moss and showed that secondary metabolites like stictic acid and nonstictic acids produced by certain species of lichen were responsible for their unpalatability to the mites. Haq (1984) worked out the role of a lohmanniid mite, *H. hirsutus* in wood decomposition and the possible role of microflora in the process of wood digestion. Ramani and Haq (1984b) conducted a survey on the association of oribatid mites with economically important plants. Luxton (1984) explained the seasonal variation in the food habits of macrophytophagous phthiracarid mites by scanning the food boli in their gut. He reported the association of microbial fauna in the food boli of *S. spinosus*. Balakrishnan and Haq (1984) reported for the first time that the oribtid genus *Hypozetes* and species *G.flabellifira orientalis* as vectors of cestode parasites. Purrini and Bukva (1984) elucidated the presence of microorganisms like bacteria, fungi, and protozoans in the gut and body cavity of many species of oribatid mites. Several species of bacteria were isolated from the alimentary tract of two species of oribatids, viz., *Rhysotritra* sp. and *Pergalumna* sp. by Wolf and Rockett (1984). The authors noted that the microorganisms in the oribatid gut changed with the species and their habitat.

Norton (1985) observed that oribatid mites could directly affect soil structure by ingesting particulate food and producing discrete faecal

pellets. According to him saprophagous and mycophagous oribatid mites possessed an active gut microfauna which changed on diet change. Cancela Da Fonseca (1985) revealed the profound effect of food characteristics on the spatial distribution of oribatid mites in a particular microhabitat. Biodegradation of cellulose in the gut of *H. hirsutus* was studied by Haq (1987) with respect to its microbial fauna. It was found that microbial involvement was higher in the tritonymph and adult when compared to other immature stages. Haq and Ramani (1987) reported the association of twenty one species of oribatid mites with the weed plants *C. odorata* and *E.crassipes*. The authors stressed the role of oribatid mites in the control of these weeds. Association of oribatid mites with moss was studied by Lawrey (1987). He reported that moss provided food, concealment, camouflage and dispersal facilities for these organisms. Quantitative aspects of the feeding behaviour of some important oribatid mites like *P. borealis, N. borassicus, Damaeus diversipilus* and *Podoribates longior* were worked out by Reutimann (1987). Purrini (1987) reported the high rate of infestation of soil oribatids by several species of protozoans in polluted locality. Fujikawa (1987) described the biological features of *P. insignis* and the gradual changes underwent by the mite community as the nature of farming progressed.

Haq (1988) studied the biology of oribatid vectors belonging to the families Scheloribatidae and Galumnidae. Neena and Haq (1988) studied the feeding specificity of six species of soil oribatids and observed similar feeding trends in field and laboratory except in one species, viz., *Bicyrthermannia duodentata*. Haq and Konikkara (1988) evaluated the role

of microbes in two oribatid mites viz., *H. singularis* and *H. hirsutus* and stated that the feeding activity of the mite relied on the microflora present in the feeding habitat. Sheela and Haq (1988) conducted a survey on oribatid mites associated with *E.crassipes*. The authors reported the presence of leaf parts in the stomach of the mites. Hagvar (1988) studied succession of microarthropods in decomposing spruce needles over a period of ten years and found that mite population attained maximum density after five years. Biological features of the oribatid mite *O. nova* were studied by Fujikawa (1988) in a nature farming field in Japan. The same author provided information on the biological features of *Tectocepheus velatus* and *T.cuspidentatus* (1988a). Norton *et al.,* (1988) studied the biology of the oribatid mite *Mucronothrus nasalis* found in cold, hard water spring brook near Toronto, Canada. The authors observed that adults and immatures were generalised grazers on unicellular and filamentous algae and fungi.

While discussing some unusual behaviour pattern exhibited by oribatid mites, Haq (1989) showed the dependence of mites on food sources of animal origin by predation and ingestion of cestode eggs. Seniczak (1989) observed that the oribatid species *Melanozetes mollicomus* preferred humid habitats of deciduous and mixed forests of medium fertility. Sanyal and Das (1989) found many species of oribatid mites attacking the apical portion of the root of pineapples.

Haq *et al.,* (1990) reported the peculiar association of a few species of oribatid mites with termites and found that majority of these mites were microphytophages feeding on fungus cultivated by termites.

Feeding habits of selected members of Lohmanniidae and Phthiracaridae were studied by Ramani and Haq (1990) who showed the wood boring and leaf skeletonising ability of these mites. They found that the process was assisted by microbial association which released necessary enzymes for cellulolytic activity. The same authors (1990a, 1990b) described two new species of oribatid mites, viz., *Uracrobates indicus* and *Notogalumna nortoni* from the crown of coconut palms. Norton (1990) gave a description of mouth parts and feeding biology of oribatid mites. Sumungala and Haq (1990) studied the feeding behaviour of *G. cuneata* and *G. alata*. The authors observed that the adult mites exposed delicate mesophyll tissue of the host plant by feeding activity which was fed by immature stages.

Dennis *et al.*, (1991) gave an interesting report on acarodomatia or mite houses on fossil leaves of *Elacocarpaceae* and *Lauraceae* which might have maintained leaf hygiene. The extreme adaptability of oribatid mites to occupy newer habitats was brought to light by Ramani and Haq (1991). The authors reported that mites originally adapted for soil life could lead an arboreal life when their habitat was destroyed. The potential of *M. degradatus* and *X. rhomboides* in the degradation of higher plant material was revealed by the same authors (1991a). Their study revealed that *X. rhomboides* was panphytophagous with eurytypic feeding habits, while *M.degradatus* was a macrophytophage. Influence of *Tyrophagus putrescentiae* and its associated bacteria on the distribution of some soil micromycetes was discussed by Smrz *et al.*, (1991). The author reported that the feeding activity of the mites damaged the fungal

hyphae and released nutritional sources for associated bacteria. Neena and Haq (1991) studied the influence of food on the development of *O. kuhnelti*. The same authors (1991a) reported the occurrence of a large number of protozoans in the gut and body cavity of ten different species of oribatid mites. Sheela and Haq (1991) explored the possible role of oribatid mites as bioindicators of soil moisture. Haq *et al.,* (1991) reported the presence of fungal hyphae in the gut of *S. fijiensis*. Sumangala and Haq (1991) studied the influence of food on the development of *G. cuneata*. Haq (1991) observed that members of Scheloribatidae were able to survive on almost any type of food and could live in association with a variety of plants. The same author (1991 a) reported that mites infected with nematodes were reluctant to consume food.

Haq and Shereef (1992) reared *Galumna uniqua* on five different species of fungi. The biology of another species of the genus viz., *G. triquetra* was traced by Shereef and Haq (1992) by rearing it on the preferred food, *Curvularia geniculata*. Haq (1992) gave a detailed report on the beneficial aspects of oribatid mites, highlighting the potential of these mites in biodegradation, bioindication and natural predation. According to Neena and Haq (1992, 1992a) mycophagy, the habit of feeding on fungal tissues was common among oribatids. The authors stated that Oribatei Superiores thrived well on fungi compared to Oribatei Inferiores. Jaikumar *et al.,* (1992) collected twenty one species of oribatid mites from coconut palms. Ramani and Haq (1992b) gave data on global distribution pattern of the various species of *Lohmannia*. Sumangala and Haq (1992) noticed that *O. terebrantis* formed feeding

galleries in the form of linear tunnels, running between the veinlets of the leaves of *E. crassipes*.

Behan (1993a) gave information on the diversity and distribution of oribatid mites. Nematophagy in oribatid mites was reported by Ravindran and Haq (1993). The authors showed that *G.flabellifera* and *X. seminudus* fed on the plant parasitic nematode *Hoplolaimus* sp. collected from rhizosphere of banana roots. Ramani and Haq (1993) studied the influence of food on development of *Allonothrus giganticus* and reported that yeast enhanced development of the species.

Role of oribatid mites in soil ecosystem was reviewed by Haq (1994). The report highlighted the influence of these mites in the maintenance of soil fertility. Smrz (1994) reported behavioural and histological responses of oribatid mites under the conditions of extreme humidity combined with microorganisms. Wrensch *et al.,* (1994) studied the cytogenetics of holokinetic chromosomes and inverted meiosis in mites. Steiner (1995) studied the influence of air pollution on oribatid mites and concluded that pollution could adversely affect the species composition and population density of these mites. Block and Convey (1995) gave a detailed report on the biology, life cycle and ecophysiology of the Antarctic mite, *Alaskozetes antarcticus*. Sumangala and Haq (1995) reported that the oribatid mite, *O.terebrantis* developed unique feeding strategies for a successful phytophagous habit. The same authors (1995a) studied nutritional diversity of different species of Acari infesting *E.crassipes*. The authors observed five different feeding groups based on

the nature of feeding. Oppedisano *et al.,* (1995) described the signalling structures in *Pergalumna* sp.

Haq (1996) described microbial involvement in the feeding habits of oribatid mites. The same author (1996a) studied nutritional diversity of oribatid mites which exhibited predation, parasitism and phytopahgy. Irmler and Pfadenhauer (1996) reported that oribatid communities in the soil showed variation depending greatly on the nutrient richness. Crossley (1997) attempted to evaluate the energetics of oribatid mite population based on their contribution in mineral and nutrient cycling. Skubala's (1997) investigations showed that oribatid mites could thrive equally well on post-industrial dump containing zinc and iron. Shtanchaeva (1997) made a comparative study of oribatid mites inhabiting soil cover lichens and epiphytic lichens. Dinesh *et al.,* (1997) carried out studies on the abundance of oribatid mites in a forest ecosystem. The authors found that mite abundance was closely related to changes in the proportion of organic carbon and the C : N ratio in the soil. Ramani and Haq (1997) described a new species of oribatid mite living on coconut palm.

The importance of oribatid mites in the decomposition of organic matter and their influence in the edaphic trophic chain of two forests under Mediterranean condition was worked out by Andre and Binche (1998). Hansen *et al.,* (1998) showed that the diversity and composition of oribatid mite fauna inhabiting soil litter depended on its complexity and composition. Food preferences in various oribatid mites were worked out by Maraun *et al.,* (1998a). Maraun *et al.,* (1998b) studied the

effects of panphytophagous oribatid mites on the recovery of microbial community in F-layer material of soil which was disturbed by human activities. Maraun and his colleagues (1998c) investigated feeding preferences for microfungi of six oribatid mites from ten beech forests. Their study revealed that mites selectively fed on fungi of superior quality which would produce more effective exoenzyme. Pinto *et al.,* (1998) exposed oribatid mites to cestode eggs and studied the duration of infestation in different species of mites and the stage in the life cycle when infection occurred. Franklin *et al.,* (1998) conducted a study on populations of arboreal oribatid mites in two flooded forests from central Arizaona. The authors reported that the reactions of the oribatid mite fauna were related more to the absence of food caused by long submersion of the stems. Studies conducted by Connell *et al.,* (1998) showed that soil oribatids exhibited a low degree of food resources specialisation. Migge *et al.,* (1998) noticed a strong decline of oribatid mite densities parallel to the distinct stratification of organic layers of pure and mixed stands of beech and spruce. Hulsmann and Wolters (1998) reported that different tillage practices had an adverse effect on microphytophagous oribatid mites.

Behan and Paoletti (1999) gave a detailed account of the general ecology, biology and life history of oribatid mites inhabiting the organic horizons of soil. Vertical distribution abundance and biology of oribatid mites developing inside spruce needles in a podosol soil profile was studied by Edsberg and Hagvar (1999). They showed that colonisation of decomposing spruce needles by mites increased with increasing depth

level in the soil. Hansen (1999) observed significant increase in endophagous oribatid mites that burrowed deep into the plant material. This activity of the mites accelerated the decomposition process. By conducting litter bag experiments, Heneghan *et al.,* (1999) showed that oribatid mites constituted a dominant component of soil fauna involved in the decomposition of a single substrate *Quereus parinus.* Litter soil mite fauna and the physiochemical conditions of soil were assayed in *Eucalyptus* and *Acacia* plantations under local conditions by Jain *et al.,* (1999). Kaneko and Salamanca (1999) compared decomposition rate and soil microarthropod abundance. The authors found that community structure and species richness of oribatid mites were higher in mixed litter. Edsberg (1999) investigated the role of soil mesofauna on the decomposition of spruce needles in forest with podosol soil. The author found oribatid mites like *S. striculus, R. ardua* and *Adoristes ovatus* developing inside decomposing spruce needles. Badegjo *et al.,* (1999) showed that density of oribatid mites decreased in a fallow that was burnt annually. Undisturbed bush fallow had a high density of oribatid mites. Haq (1999) reared oribatid vectors in culture vials by offering preferred food and eggs of tape worm.

Community analysis of oribatid mites was conducted by Hong Hyun and Joonho Lee (2000) in Nanson and Kwangriung coniferous forest in Korean republic which has been subjected to different degrees of environmental pressures. Species abundance, biodiversity, distribution and population dynamics of oribatid mites from rice fields in Beijing and Anhui in China were studied by Tian *et al.,* (2000). The

feeding habit of the panphytophagous species, *S.laevigatus* on litter of meadow grass, *Holeus lanatus* was studied by Hubert *et al.*, (2000). The authors described the microanatomy of the digestive tract of oribatid mites. They also isolated fungi from the digestive tract of these mites. Schuster *et al.*, (2000) artificially infected six species of oribatid mites with eggs of *Moniezia expansa* and studied their vector role. Maraun and Scheu (2000) investigated the role of the quantity and quality of food on the relative abundance of oribatid mites from different sites in Europe and Germany. Kuriki (2000) studied ecology of oribatid mites in Sphagnum mines in Japan. He observed high density of oribatid mites under conditions of excess food materials and sufficient microhabitat combined with a low predation pressure. Studies conducted by Gonzalez and Seastedt (2000) proved that taxonomic diversity of oribatid mites was positively correlated with plant litter decomposition. Johnston (2000) stressed the role of oribatid mites in the formation of above ground food webs. He suggested that oribatid mites acted as a potential food source for macroarthropod and vertebrate predators of the forest floor. Behan and Walter (2000) studied the biodiversity of oribatid mites feeding in tree canopies and litter.

Ramani and Haq (2001) examined the potential role of two species of oribatid mites in biodegradation of organic matter. Results of their investigation clearly showed the ability of *Hoplophthiracarus rimosus* and *Lohmannia* sp. to degrade higher plant materials, particularly woody elements. The result was confirmed by enzyme assays which demonstrated the release of cellobiase by both species. Haq and

Sumangala (2003) studied the acarine regulators of water hyacinth and pointed out that the oribatid mite *O. terebrantis* was highly injurious to this weed plant and can be used as an effective regulatory agent in combination with other mites. Feeding activity of the mite caused mechanical damage of leaf tissue. Jain and Neha (2003) studied the role of oribatid mites in decomposition and mineralization of decaying plant parts including root and leftovers after harvesting of crops. In his exhaustive study on bioprocessing of plant litter in tropical ecosystem, Haq (in press) showed that utilization of oribatid mites for mass production of energy rich faecal pellets deserves special emphasis in soil productivity.

PART II
MATERIALS AND METHODS

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

MATERIALS AND METHODS

1. Extraction of Live Mites

Procurement of sufficient number of live specimens constitute one of the most important basic requirements for the biological study of any organism as in the case of mites. Accordingly, soil samples from the different study sites were frequently collected for detailed biological studies. These samples were subjected to extraction using a Berlese - Tullgren apparatus. Live mites were extracted into collecting vials containing moistened leaf powder or water. After extraction, vials containing water were filtered and allowed to dry for 5-10 minutes in air. Live mites while moving were picked up using moistened hair brush under a stereomicroscope. Vials containing leaf powder along with mites were transferred to petridishes, kept for a few minutes under a 40W bulb. The mites were then collected and sorted out and transferred to culture vials for further studies.

2. Culture of Mites

2a. Preparation of culture vessels

In the laboratory, mites were cultured in specially designed culture vessels made up of plastic. The culture medium was prepared by mixing Plaster of Paris and charcoal in the ratio 4:1. This mixture was made into a smooth paste with distilled water. A few drops of 1% thymol solution were also added into the mixture as a fungicide. This mixture was carefully poured into plastic containers having 3-5cm

diameter and 4cm height. Care was taken to prevent trapping of air bubbles while pouring the medium. The surface of the medium was made smooth and even and the vessels were allowed to set and dry for two days. The medium was then kept moist by adding a few drops of distilled water. Minute pin holes were made in the lids of these culture vessels to maintain air circulation (Plate-44, Figs. 1 & 2).

2b. Collection and maintenance of food substances

As the present study was intended to examine the biodegradation potential of oribatid mites, they were reared in the laboratory on various food substances of higher plant origin. For this, leaves and wood pieces from the four study sites were collected in plastic bags with proper labels and were brought to the laboratory. From site UC, leaves and wood pieces of *Mangifera indica, Artocarpus heterophyllus, Ficus benjamina, Anacardium occidentale, Acacia auriculiformes* and *Bambusa arundinacea* were collected. Leaves and wood pieces of *Xylea zylocarpa* in various stages of decomposition were collected from site KS. Drift wood in different stages of decomposition and decaying leaves and roots of *Calotropis gigantea* were collected from site CB. Leaves and wood pieces of *Tectona grandis, Samanea saman* and *Terminalia catapa* were obtained from site GC. Wood pieces were cut into small pieces of about 1cm long and 0.5cm thickness and kept soaked in distilled water. 3-4 leaves of the same species were stapled together and then cut into squares of 0.5cm and kept soaked in distilled water. Wood and leaf pieces prepared in this way were used as food for rearing the mites. Leaf/wood samples of

12 different species of plants were thus prepared and kept as stock food for rearing oribatid mites in the laboratory.

2c. Culture of Oribatid mites

The extracted live mites were grouped according to species and were transferred to the prepared culture vessels. The mites were then offered the respective leaves/wood pieces as food depending on the site of their collection. The food item was provided at the centre of the culture vessel and the mites were introduced subsequently. Extreme care was taken to maintain optimum conditions of sanitary, temperature and humidity of culture vessels. The culture vessels were observed regularly thrice a day and one or two drops of distilled water were added. Mites were allowed to acclimatize in these culture vessels for about one or two weeks, after which individual culture vessels were set up for various biological studies. Individual culture vessels were prepared by introducing 10 mites into each culture vessel. Based on the food preference of each species of mite, appropriate food items were provided in the culture vessels. The preferred food of each mite was identified by conducting laboratory food preference tests followed by gut content examination.

3. Analysis of Gut Contents

An analysis of the gut contents of field collected individuals helped to identify the feeding preference of oribatid mites in natural condition. Live mites extracted through Berlese funnels were washed in distilled water and kept in culture vessels without providing food.

These mites were then transferred to microscopic slides. Food boli and gut contents of the mite were dissected out by exerting a slight pressure with the blunt end of a dissecting needle. The contents were spread out evenly in glycerine and observed under a research microscope. Stains were applied for better observation of plant and fungal material as follows. After proper staining, identification of gut contents was carried out following Johansan (1940) Prasad and Prasad (1975), Berlyn and Miksche (1976), Gahan (1984), Dwivedi and Singh (1990) and Sanderson (1994).

1. Anilin blue: 1% aqueous solution of anilin blue was used to stain fungal hyphae and spores.
2. Erythrosin: 1% solution of erythrocin in 95% alcohol was used to stain algal sheaths.
3. Bismark brown: 2% solution of bismark brown in 70% alcohol helped to stain cellulose cell wall.
4. Safranin: 2.25gm of safranin dissolved in 225ml of 95% alcohol was used for staining fungal filaments.
5. Malachite green: 0.5% solution of malachite green in 95% alcohol stained lignified cell wall.
6. Crystal violet: 1% solution of crystal violet in clove oil was used to stain chitinized cell wall.
7. Basic Fuchsin: 1gm of basic fuchsin dissolved in 100ml of 95% alcohol and then diluted with 10ml distilled water was used to stain vascular system of higher plants.
8. Carbol Fuchsin: 0.3 gm of basic fuchsin dissolved in 100ml of 5% carbolic acid was used for staining bacteria.

In addition to the analysis of gut contents of the mites, food boli of live as well as preserved mites and faecal pellets egested by mites were also subjected to examination as described above for drawing conclusion.

Results of the gut content analysis were utilised to group the mites into three feeding categories. Mites whose gut contents revealed the presence of higher plant materials were regarded as macrophytophagous, those with fungi and bacteria as microphytophagous and those with a wider choice of food as panphytophagous.

4. Laboratory Feeding Experiments

Oribatid mites whose gut contents revealed the presence of woody and leafy materials were chosen for feeding experiments. This helped to confirm the results of gut content analysis and feeding preferences of oribatid mites. For this, mites were reared in separate culture vessels, offering them food items already kept ready. Each feeding test was repeated three times before arriving at a conclusion of the preferred food of individual species. The preference of a particular species of oribatid mite to a specific type of food item was determined based on the following parameters.

1. Presence of the mites near or among the food item.
2. Presence of feeding marks produced in/on the food in the form of skeletonization of leaves, feeding holes and burrows on leaves and wood pieces.

3. Number and rate at which faecal pellets were produced by the mites.
4. Observing the general appearance and activity of mites.
5. Appearance of eggs/ spermatophores/ immatures in the culture vessels.

By employing appropriate symbols, the degree of preference of individual mite species to particular type of food was represented. The pattern followed in the present study was as given below:

O - Rejection
A - Low feeding producing one faecal pellet per day per mite.
A^{+} - Moderate feeding producing 2-3 faecal pellets.
A^{++} - Intense feeding producing more than 3 faecal pellets.
R - Reproductive capability producing eggs/spermatophore
O - Rejection A - Acceptance R - Reproduction

5. Structural Analysis of Gnathal Appendages

Gnathal appendages of a few representatives of oribatid mites were dissected out in glycerine and kept in slightly warm lactic acid for 20-30 minutes. They were then properly spread out on microslides and mounted in Hoyer's medium. The pedipalp, chelicera and rutellum which formed the major grasping and masticating appendages were subjected to detailed structural analysis for studying their functional role in food grasping, collection and mastication. Sketches of mouth parts were drawn and photographs were taken as and when necessary.

PART II
OBSERVATION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

OBSERVATION

1. Analysis of Gut Contents

Direct assessment of the feeding habits of oribatid mites in the field appears rather difficult. This is mainly due to their minute body size, subterraneous nature and nocturnal habit. Gut content analysis of field collected individuals offers the best solution to overcome this difficulty. Quite often, it will be a direct reflection of their feeding trends in natural habitat. Accordingly, out of the 58 species of oribatid mites collected, 31 species were selected for gut content analysis. Of the 31 species selected, 24 belonged to Oribatei Inferiores and the remaining seven to Oribatei Superiores. Whenever gut contents were not sufficient enough to determine feeding specificity food boli and faecal pellets were also subjected to microscopic observation.

Results of the gut content analysis are represented in Table 8. Accordingly, 21 out of the 31 species studied or 68% were found to be macrophytophagous, six species or 19% panphytophagous and the remaining four species or 13% microphytophagous, based on types of food materials recovered from the gut of these mites. In live mites, the gut contents appeared in the form of food boli within the abdomen. The number and size of the food boli depended on the extent of occurrence of the preferred food in the habitat and its stage of digestion. The gut contents of the mites studied consisted of a variety of food items like bacteria, fungal hyphae and spores, algal and moss cells, pollen grains, leaf and wood particles and some unidentified

components. The type and proportion of the food items present varied from one species to the next.

Gut contents of 21 species exhibited the presence of particles of higher plant origin in different stages of digestion. These were identified as partially decomposed woody and leafy materials, pollen grains, fibres, parenchymatous cells, xylem vessles, pitted vessels and spiral thickenings. Accordingly, these 21 species could be categorised as macrophytophagous in the field condition. Surprisingly, all of these 21 species belonged to Oribatei Inferiores. Members of the family Phthiracaridae showed predominance of woody elements in their gut. Varying amounts of leafy material also were recovered from their gut. The predominance of woody elements in the gut of *P. haqi* over leafy material was quite obvious. Substantial amount of highly triturated wood particles could be observed in the gut of *A. (H.) chaliensis* (Plate-44 · Fig.3). Traces of fungal hyphae were detected in the gut contents of immature stages of *A. (H.) reticulatus,* but the gut of adults never revealed the presence of fungal hyphae. At the same time moderate amount of leafy materials were always present in their gut along with woody tissue. *A (H.) crenulus* and *A. (H.) keralensis* showed the presence of digested wood particles along with leaf bits.

A total of 16 species of lohmanniid mites belonging to eight genera were dissected out to study their gut contents. Members of seven out of the eight genera studied revealed the predominance of leafy material in their digestive tract over any other food item. The only exceptional genus to this was *Heptacarus* whose gut was found carrying

woody parts in various stages of decay. Shredded woody elements showing pitted vessels in advanced stages of digestion were detected in the gut of *H. indicus* (Plate-44, Fig. 4). In fact these mites were collected from the decaying drift wood and wood of *C. gigantea* present in Chaliyam beach soil. The gut constituents of *A. mahabaeus. A. malabaricus* and *A. plumosus* disclosed the occurrence of partly digested leaf lamina along with traces of woody tissue. Similarly, *C. denrisetosus, H. porosus, H. xavieri, H. davisi, J. kuhnelti, J. reticulatus, J. minutus, V. arboriformes, V. ramaniae, M. degradatus, P. undirostratus* and *P. elongatus* were proved to be good leaf eaters. Green coloured cellular remnants and spiral thickening were detected in the gut of *H. davisi* (Plate:44 Fig.5). Gut contents of *M.dgradatus* contained partly digested leaf tissue (Plate-44, Fig. 6).

Gut contents of the two lower oribatid mites *A. giganticus* and *A.longisetosus* revealed bacteria, leafy elements and fungal components in a highly advanced state of decay. Partly digested epidermal cells were identified in the gut of *A. giganticus*. Presence of fungal spores was noted in *A. longisetosus*. Parenchymatous cells, xylem vessels and other highly digested plant particles along with fungal spores were present in the gut of *M. glabrus* (Plate: 45 Fig. 1). But woody elements were absent in the case of *S. decarinatus*, instead large quantities of leaf components and fungal hyphae were detected. *X. seminudus* was unique in that in addition to woody, leafy and fungal elements (Plate-45, Fig. 2), bacteria and unidentified animal matter were also present in their alimentary tract. The higher oribatid mite, *G. flabellifera* was found to have a varied

diet consisting of bacteria, fungi, algal and moss cells, leaf and woody particles and different types of pollen grains.

Three species of mites viz., *B. retiarius*, *O. kuhnelti* and *P. malabarica* were common fungal feeders. Their gut contents revealed an abundance of fungal hyphae and spores in different stages of digestion. Semi digested fungal spores and hyphae were observed in the case of *P. malabarica* (Plate: 45 Fig. 3), while asco spores and fungal mycelium were detected in *B. retiarius* (Plate-45, Fig. 4). *A. pantotrema* appeared to be a bacterial feeder as no other lower or higher plant element could be detected in its gut content.

2. Laboratory Feeding Experiments

Oribatid mites whose gut contents proved the presence of higher plant elements were selected for laboratory feeding experiments. A total of 27 species of oribatid mites were reared in the laboratory. Out of this 23 belonged to Oribatei Inferiors and four belonged to Oribatei Superiores. Mites were provided with wood and leaves of 11 different higher plants and drift wood collected from the four different study sites as food. Table 9 provides a comparative account of the different types of food offered to the oribatid mites, their feeding preferences and the result of feeding on survival and reproduction. The table shows that the 27 species of oribatid mites studied showed varying levels of preferences towards the different types of higher plant elements, substantiating the results of gut content analysis. All the members of inferior oribatids were seen to be active feeders of one or a few of these

food items and were even noticed to deposit eggs and spermatophores. Intense feeding by immature stages was also observed in certain cases.

Members of the family Phthiracaridae were found to be primarily wood feeders though very rare instances of leaf feeding could also be observed. *A. (H.) chaliensis* and *A. (H.) crenulus* (Plate-46, Fig. 2) exhibited a similar type of feeding habit as both fed actively on the wood of *C.gigantea,* on which they reproduced. Young ones grew feeding on the same item. Both species could reproduce on drift wood also but the immatures did not appear to relish it as food. The only difference between the two species noted was that *A. (H.) crenulus* exhibited a low feeding preference towards leaves of *C. gigantea* . *A. (H.) reticulatus* fed on seven wood items (Plate-46, Fig. 1)and a single leaf item. A low level feeding on the leaves of *A. heterophyllus* was evident. The mites were seen to reproduce successfully only when fed on the wood of *M. indica* or *A. heterophyllus.* Nymphal feeding was also noticed on these two items. *A. (H.) keralensis* exhibited a wider choice of food item as it fed on 11 items offered. The plants avoided by the above mites were *A. auriculiformes* and *S. saman.* But the mites attained reproductive success only on the wood of *M. indica* which was intensely fed by immatures also. *P. haqi* avoided *F. benjamina, A. auriculiformes* and *B. arundinacea.* It fed on the wood of all other plants but reproduced only on wood of *X. zylocarpa.* This formed the food of immature stages also.

An interesting aspect of phthiracarid feeding observed was that all the species studied completely rejected *A. auriculiformes.* Drift wood of Chaliyam beach was found palatable to all the five species though

nymphs did not show any preference towards this item. All these five species exhibited wood boring and tunnelling habit forming cavities and irregular channels within the wood pieces offered (Plate-45, Figs. 5 & 6; Plate-46, Fig. 1). Quite often these cavities and channels became packed with faecal pellets (Plate-45, Figs-5 & 6; Plate-46, Fig. 2). The colour of the faecal pellets reflected the colour of the food consumed. *A. (H.) chaliensis* and *A. (H.) crenulus* produced dark brown faecal pellets. Densely packed faecal pellets intermingled with solitary eggs and juvenile stages were of common occurrence in the feeding tunnels of *X. zylocarpa* as was seen in the case of *P. haqi*. Continued feeding by adults and immatures transformed the wood piece into shreads which were finally converted into a heap of faecal pellets.

Members of the family Lohmanniidae exhibited a general preference to higher plant materials more specifically towards leafy components. Results of the feeding experiments disclosed this nature of 15 species as shown in Table 9. Feeding by *H. xavieri* and *A. malabaricus* produced small holes and cavities in the leaf tissue packed with faecal pellets (Plate-46, Figs. 3 & 4). *A.malabaricus* often selected feeding site close to the mid rib of leaves specifically on the soft parenchymatous tissue. Adults and immatures of *H.davisi* were seen attracted to moistened and partly decomposed leaves of *X. zylocarpa* (Plate-46, Fig. 6). Immatures were seen nibbling away the soft mesophyll tissue while adults attacked harder tissue gradually leading to its skeletonization (Plate-47, Fig. 2). *A. mahabaeus* released faecal pellets at random so that within a short period of one week the entire surface of the culture vessel

was found covered with them (Plate-46 , Fig. 5). *H. porosus* was seen feeding at the edges of leaf bits, depositing faecal pellets close to the feeding sites (Plate-47, Fig. 1) *H. xavieri* was seen attacking the more resistant midrib.

Feeding of *M. degradatus* on leaf of *X. zylocarpa* was so intense that even leaf lamina, veins and veinlets were devoured by adults and immatures (Plate-47, Figs. 5 & 6). Their voracious feeding led to the production of cavities in the offered food, leaving the leaf tissue completely skeletonised. The pattern of feeding was more or less same for other lohmanniid genera like *Javacarus* and *Papillacarus*. *Cryptacarus* and *Vepracarus* fed on both leaves and wood. But *C. dendrisetosus* and *V. ramaniae* were noticed to attain reproductive capability when leaves of *X. zylocarpa* was given as food. *V. arboriformes* required leaves of *B. arundinacea* as food to produce eggs and spermatophores.

But *H. indicus* was totally different from other lohmanniid mites. It could consume the partly decayed wood of *C. gigantea* and drift wood offered, producing holes and tunnels in the wood (Plate-47, Fig. 3 &4). Like the members of Phthiracaridae, they bored into the wood pieces forming lengthy burrows and tunnels within which eggs were laid. Immature stages were often seen in these tunnels.

The other two lower oribatid mites studied viz., *A. giganticus* and *A. longisetosus* had a wider choice of food. *A giganticus* did not show any affinity towards *A. occidentale* and drift wood while *A. longisetosus* consumed almost all types of leaves and avoided wood.

All the four higher oribatids studied also exhibited variety in their feeding habits utilising either leaf or wood or sometimes both. *M. glabrus* completely avoided. *F. benjamina, A. auriculiformes, S. saman* and drift wood. *X. seminudus* avoided wood of *A. auriculiformes.* It fed voraciously on drift wood, boring and tunnelling into wood as they fed. Adults were seen to reproduce successfully on most of these items, but immatures failed to utilise these materials as food. *G. flabellifera* was found to be a versatile feeder as it avoided only *T. grandis, S. saman* and *T. catapa.* But surprisingly, they were found unable to reproduce when fed on these items. Cultures though were maintained over a period of 5-6 weeks, they could not continue life further and mortality resulted.

Feeding responses of oribatid mites to various food items provided are presented in Plate 48. While analysing the feeding responses of the 27 species of oribatid mites to the different plant materials provided as food, 13 species of oribatid mites were found to reproduce successfully on leaf or wood of *X. zylocarpa.* 10 other species showed positive trend towards this food item. *M. indica* was also used by 23 species as food while reproduction was restricted to 10 species. *A. heterophyllus* was fed by 22 species and helped reproduction and nymphal feeding of 12 species. 19 species used *A.occidentale* but only one species attained reproductive success. 18 species used *F. benjamina* as food but none attained reproductive success. *B.arundinacea* was used as food by 12 species which afforded reproductive ability for seven species. Though 13 species showed a positive reaction towards *T. grandis* only two species succeeded in reproducing on this diet. 12 species of

oribatid mites fed on *T. catapa* and two members successfully reproduced on it. *C. gigantea* was used as food by 10 oribatid species. This item helped three species to reproduce. *S. saman* was accepted as food by 11 species but none attained reproductive ability when fed on this food. Drift wood was consumed by 11 species which allowed reproduction and nymphal feeding of four members. The minimum feeding response was towards *A. auriculiformes* which was accepted by seven species, two of which reproduced on this item followed by nymphal feeding.

3. Structural Analysis of Gnathal Appendages

Detailed analysis of gnathal appendages established it as an efficient tool in categorising nutritional status of oribatid mites. As a general rule structure of gnathal appendages proves to be a reflection of a particular feeding mode in most of the animals. Accordingly, attempts were made here to study in detail the gnathal appendages of 23 species of oribatid mites representing the major feeding groups included in the present study. The gnathal appendages of oribatids are of the chelate-dentate type and consist of rutella, chelicera and the pedipalp. Of these, the first two consist of the main masticator organs and the third is used as a grasping one.

Macrophytophagous phthiracarid mites primarily depend on woody tissues and hence designated as xylophage. Chelicerae (Plate-49, Figs. 1 & 2) in them were found to be broad and stout with denticulated body. Chelae were well developed and sclerotised. Both movable and fixed digits carried 4-5 teeth. This helped cutting of the hard wood

pieces. The rutellar dendites were provided with prominent dorsal concavities referred to as the vestibules. This helped to accommodate large and hard wood pieces for the masticatory action of chelicerae. *A. (H) chaliensis* (Plate-49, Fig. 1) and *P. haqi* (Plate-49, Fig. 2) possessed the above structural adaptation. Pedipalp with its distal eupathidia helped to feel the food and hold it in position.

Macrophytophagous species which primarily feed on leafy tissues are categorised as phyllophages. Lohmanniid mites studied belonged to this category. The labiogenal suture had a lesser concavity than that of xylophages in this group. Leaf which formed their main food was not as hard as wood. It could be folded in any direction to be accommodated within this space. Chelicerae were less broader, elongated or with round base (Plate-49, Figs. 3 & 4). The movable digit had 3-4 teeth while the fixed digit had 2-3. This helped cutting of leaf into smaller particles. The rutella had a broader distal end and a narrow proximal end bearing 3-4 notches distally. It appeared flat, more or less triangular in shape and strongly sclerotised. Members of Lohmanniidae like *A. malabaricus* (Plate-27, Figs. 2 & 3), *A. plumosus* (Plate-29, Figs. 2 & 3), *H. xavieri* (Plate-31, Figs. 2 & 3), *H. davisi* (Plate-49, Fig. 4), *H. indicus* (Plate-35, Figs. 3 & 4), *J. minutus* (Plate: 49, Fig.3), *C. dendrisetosus* (Plate-50, Figs. 1 & 2), *V. aroboriformes* (Plate-38, Figs. 2 & 3), *V. ramaniae* (Plate-40, Figs. 2 & 3) and *P. elongates* (Plate-42, Figs. 2 & 3) possessed these structural peculiarities.

Mouth parts of two microphytopagous species were studied in detail. *P. malabarica* (Plate-49, Fig. 6; Plate-50, Figs. 3 & 5) possessed a

narrow and compressed and more or less triangular rutella. The free end of rutella carried 3-4 sharp notches distally. Chelicerae were narrow and elongated. The movable and fixed digits carried 3-4 small but sharp teeth. This was advantageous to cut fungal hyphae and mycelium. In *A. pantotrema* (Plate-50, Figs. 6-8) rutellum was simple and narrow with three sclerotised notches. Chelicerae appeared strong but elongated and narrow. Movable and fixed digits possessed three small teeth suited for devouring very minute particles. In both the above cases the gnathal appendages were organised in such a way that only very small particles could be accommodated between the rutellae.

Gnathal appendages of six panphytophagous oribatid mites were studied in detail. *A. giganticus* (Plate-50, Figs. 9-10) possessed a narrow rutellum with three blunt notches distally. Chelicera was remarkably elongate and thin. Movable digit carried 3-4 conical and widely separated teeth while fixed digit had 2-3 teeth. This helped efficient handling of almost any type of food. In the case of *A. longisetosus,* rutellum was rectangular and narrow with three distinct notches. Chelicerae were broad and short. Digitus mobilis carried 3-4 teeth and digitus fixus carried three (Plate- 50, Figs. 11 & 12). In *M. glabrus* (Plate-43, Figs. 4 & 5), rutellum was broad ending in three blunt notches. Chelicerae were strong, thick and broad. Digitus mobilis carried three and digitus fixus carried two teeth. In *S. decarinatus* (Plate-51, Figs. 1 & 2) rutellum was broad and sclerotised with three indistinct notches. Rutellum possessed a rutellar brush with fine setae on either side. Chelicerae were strong and well developed. Digitus mobilis carried four

teeth and digitus fixus three. In X. *seminudus* (Plate-51, Figs. 3 & 4) rutellum was broad and sclerotised with three indistinct notches. Rutellum carried a rutellar brush which was ciliated unilaterally. Chelicerae were well developed. Digitus mobilis carried three teeth and digitus fixus two. Rutellum in G.*flabellifera* (Plate-51, Figs. 5 & 6) was thin, and somewhat pointed. Chelicerae were long, thin, strong and well sclerotised. Both digits carried two well sclerotised teeth.

Organisation of gnathal appendages in all the above panphytophagous species allowed accommodation of any type of food between the rutellae. Depending upon the food, the vestibular cavity within the rutellae could be adjusted by muscular action. Chelicerae could handle hard woody tissues, rather soft leafy elements and minute fungal components equally well. Rutellar brush was useful in supporting fungal hyphae or mycelium for masticating action of chelicerae and probably direct the food particles to the rutellar gap.

Table 8 - Gut Content Analysis of Field Collected Oribatid Mites

	Mites Selected	Mites dissected	Food boli / faecal pellets analysed	Materials retrieved								Remarks
				1	2	3	4	5	6	7	8	
				Bacteria	Fungal hyphae/ spores	Algae	Moss	Leaf particles	Wood particles	Pollen grains	Others	
	I. Oribatei Inferiores											
1.	*Apoplophora pantotrema* Berlese, 1913	40	52	+++	-	-	-	-	-	-	-	Microphytophage
2.	*Atropacarus (Hoplophorella) chaliensis* sp. nov.	35	38	-	-	-	-	+	+++	-	-	Macrophytophage
3.	*A. (H.) crenulus* sp. nov.	25	28	-	-	-	-	++	+++	-	-	"
4.	*A. (H.) reticulatus* sp. nov.	32	44	-	+	-	-	++	+++	-	-	"
5.	*A. (H.) keralensis* sp. nov.	18	26	-	-	-	-	+	+++	-	-	"
6.	*Phthiracarus haqi* sp. nov.	22	30	-	-	-	-	++	+++	-	-	"
7.	*Annectacarus mahabaeus* Corpuz Raros, 1974	26	33	-	-	-	-	+++	+	-	-	"
8.	*A. malabaricus* sp. nov.	19	25	-	-	-	-	+++	+	-	-	"
9.	*A. plumosus* sp. nov.	18	22	-	-	-	-	+++	+	-	-	"
10.	*Cryptacarus dendrisetosus* Bhatacharya *et al.*, 1974	21	28	-	-	-	-	+++	++	-	-	"
11.	*Haplacarus porosus* Haq and Clement, 1987	23	31	-	-	-	-	+++	+	-	-	"
12.	*H. xavieri* sp. nov.	26	28	-	-	-	-	+++	+	-	-	"
13.	*H. davisi* sp. nov.	17	22	-	-	-	-	+++	++	-	-	"
14.	*Heptacarus indicus* sp. nov.	22	30	-	-	-	-	-	+++	-	-	"
15.	*Javacarus kuhnelti* Balogh, 1961	15	22	-	-	-	-	+++	+	-	-	"
16.	*J. reticulatus* Sengbusch, 1982	24	31	-	-	-	-	+++	++	-	-	Macrophytophage

Mites Selected	Mites dissected	Food boli / faecal pellets analysed	Materials retrieved								Remarks
			1	2	3	4	5	6	7	8	
			Bacteria	Fungal hyphae/ spores	Algae	Moss	Leaf particles	Wood particles	Pollen grains	Others	
17. *J. minutus* sp. nov.	18	26	-	-	-	-	+++	+	-	-	Macrophytophage
18. *Vepracarus arobirformes* sp. nov.	14	20	-	-	-	-	+++	+	-	-	"
19. *V. ramaniae* sp. nov.	16	26	-	-	-	-	+++	+	-	-	"
20. *Meristacarus degradatus* Haq and Jaikumar 1993	34	47	-	-	-	-	+++	++	--	-	"
21. *Papillacarus undirostratus* Aoki, 1965	12	23	-	-	-	-	+++	+	+	-	"
22. *P. elongates* sp. nov.	16	31	-	-	-	-	+++	+	-	-	"
23. *Allonothrus giganticus* Haq, 1978	32	40	+	++	-	-	++	-	-	-	Panphyotophage
24. *Archegozetes longisetosus* Aoki, 1965	28	34	+	++	+	+	++	-	+	-	"
II. Oribatei Superiores											
25. *Basilobelba retiarius* Warburton, 1912	14	21	+	+++	-	-	-	-	-	-	Microphytophage
26. *Megalotocepheus glabrus* sp. nov.	19	18	-	+	-	-	++	++	-	-	Panphytophage
27. *Oppia kuhnelti* Aoki, 1965	42	38	+	+++	-	-	-	-	-	-	Microphytophage
28. *Scheloribates decarinatus* Aoki, 1984	24	30	+	+++	-	-	++	-	-	-	Panphytophage
29. *Pelokylla malabarica* Clement and Haq, 1982	16	24	+	+++	-	-	-	-	-	-	Microphytophage
30. *Xylobates seminudus* Hammer, 1972	32	40	+	+++	+	+	+++	++	+	+	Panphytophage
31. *Galumna flabellifera* Aoki, 1965	19	26	+	+++	+	+	+	-	+	-	"

+++ Indicate presence of substance in more than 50% of mites examined
++ Indicate presence of substance in 25-50% of mites examined
+ Indicate presence of substance in less than 25% of mites examined

Table 9 - Feeding experiments of oribatid mites in laboratory

Mites selected	Food items offered																						Remarks
	Mangifera indcia		*Artocarpus heterophyllus*		*Ficus benjamina*		*Anacardium occidentale*		*Acacia auriculiformes*		*Bamboosa arundinacea*		*Xylea xylocarpa*		*Calotropis. gigantea*		*Tectona. grandis*		*Samanea saman*		*Terminalia. catapa*		Drift wood	
	1		2		3		4		5		6		7		8		9		10		11		12	
Oribatei Inferiores	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	W	
1 *Atropacarus (Hoplophorella) chaliensis.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	R	0	0	0	0	0	0	R	Xylophage
2 *A. (H.) crenulus.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	A	R	0	0	0	0	0	0	R	"
3 *A. (H.) reticulates*	0	R	A	R	0	A	0	A	0	0	0	0	A	0	0	0	0	0	0	0	0	0	A++	"
4 *A. (H.) keralensis*	A	R	0	A++	0	A	0	A+	0	0	0	A	0	A	0	A	0	A	0	0	0	A	A+	"
5 *Phthiracarus haqi.*	O	A	O	A	O	O	O	A	O	O	O	O	A	R	O	A+	O	A	O	A	O	A	A	"
6 *Annectacarus mahabaeus.*	R	O	R	O	A	O	A+	O	O	O	R	O	A	O	O	O	A	O	O	O	A	O	O	Phyllophage
7 *A malabaricus.*	A+	O	A	O	A	O	A	O	R	O	A	O	A+	O	O	O	O	O	A	O	O	O	O	"
8 *A plumosus.*	A+	O	A+	O	O	O	A++	O	O	O	O	O	A+	O	O	O	A++	O	O	O	R	O	O	"
9 *Cryptacarus dendrisetosus.*	A	A	O	O	O	O	A+	A	O	O	O	O	R	A	O	O	O	O	A	A	O	O	O	"
10 *Haplacarus porosus*	O	O	R	O	A+	O	A	O	O	O	A	O	R	O	O	O	O	O	O	O	O	O	O	"
11 *H.xavieri*	R	O	R	O	A	O	A+	O	O	O	A	O	A	O	O	O	A	O	O	O	O	O	O	"
12 *H. davisi*	A+	O	A	O	A	O	A	O	A+	O	O	O	R	O	O	O	A	O	O	A+	O	O	O	"
13 *Heptacarus indicus*	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	R	O	O	O	O	O	O	R	Xylophage
14 *Javacarus kuhnelti*	A	O	R	O	A	O	O	O	O	O	O	O	R	O	O	O	A	O	O	O	A	O	O	Phyllophage
15 *J. reticulatus*	R	O	R	O	A++	O	A	O	O	O	O	O	R	O	O	O	A+	O	A	O	A	O	O	"
16 *J. minutus*	R	O	R	O	A	O	A+	O	O	O	O	O	A+	O	O	O	O	O	A	O	O	O	O	"
17 *Vepracarus arbonriformes*	A	A	A+	O	A	O	O	O	O	O	R	A+	A	A	O	O	O	O	O	O	O	O	O	"

Mites selected	Food items offered																							Remarks
	Mangifera indcia		*Artocarpus heterophyllus*		*Ficus benjamina*		*Anacardium occidentale*		*Acacia auriculiformes*		*Bamboosa arundinacea*		*Xylea xylocarpa*		*Calotropis. gigantea*		*Tectona. grandis*		*Samanea saman*		*Terminalia. catapa*		Drift wood	
	1		2		3		4		5		6		7		8		9		10		11		12	
Oribatei Inferiores	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	W	
18 *V. ramaniae*	A	A	A	O	O	O	O	O	O	O	O	O	R	A	O	O	O	O	O	O	O	O	O	"
19 *Meristacarus degradatus*	A+	O	A	O	A+	O	A+	O	O	O	O	O	R	A	O	O	O	O	A	O	O	O	O	"
20 *Papillacarus undirostratus*	A++	O	R	O	A	O	A	O	O	O	R	A	A	O	O	O	A	O	O	O	A	O	O	"
21 *P. elongatus*	A	O	O	O	O	O	O	O	O	O	O	O	R	A	O	O	O	O	O	O	O	O	O	"
22 *Allonothrus giganticus*	R	A	R	A	A	A	O	O	A	O	R	A	R	A++	A	A	R	R	A	A	A++	A	O	Phyllophage and Xylophage
23 *Archegozetes longisetosus*	A++	O	A+	O	A	O	R	O	A+	O	R	O	R	O	A	O	A++	O	A	O	R	O	R	Phyllophage
Oribatei Superiores																								
24 *Megalotocepheus glabrus*	R	A+	R	A	O	O	A+	A+	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Phyllophage and Xylophage
25 *Scheloribates decarinatus*	R	R	R	R	A	A+	A+	A+	R	R	R	R	R	A	A+	A	A++	A	A	A	A+	A	A++	"
26 *Xylobates seminudus.*	R	A+	A++	R	A++	A	A	A+	A+	O	A++	R	R	R	A	A	A	R	A+	A+	A+	R	A++	"
27 *Galumna flabellifera*	A+	A+	A++	A+	A	A+	A+	A	A	A++	A+	A+	A+	A+	A+	A	O	O	O	O	O	O	A+	"

L-Leaf
W-Wood
O-Rejection

A- low feeding producing 1 faecal pellet per day

A+ - Moderate feeding producing 2-3 faecal pellets per day

A++- intense feeding producing more than 3 faecal pellets per day

R-Reproductive capability producing eggs / spermatophores

PLATE 44

Culture of Oribatid Mites and Materials Recovered from Gut of Oribatid Mites

Fig. 1 Culture vessels

Fig. 2 Inner view of culture cell with food.

Fig. 3 Highly triturated wood (TW) from the gut of *Atropacarus (Hoplophorella) chaliensis*

Fig. 4 Shredded wood (SW) from the gut of *Heptacarus indicus*

Fig. 5 Gut contents of *Haplacarus davisi* showing mass of spiral thickening (ST) of xylem vessels

Fig. 6 Gut contents of *Meristacarus degradatus* showing partly digested leaf tissue

PLATE 45

Materials Recovered from Gut of Oribatid Mites and Laboratory Feeding of Oribatid Mites

Fig. 1 Gut contents of *Megalotocepheus glabrus* XV. Xylem vessels, FS fungal spores

Fig. 2 Gut contents of *Xylobates seminudus* FS. fungal spores

Fig. 3 Gut contents of *Pelokylla malabrica* FS. Fungal Spores, FH. Fungal Hyphae

Fig. 4 Gut contents of *Basilobelba retiarius* FS. Fungal Spores, FM. Fungal Mycelium

Fig. 5 Burrows formed by feeding of *Atropacarus (Hoplophorella) reticulatus,* B. Burrow, FP. Faecal Pellets

Fig. 6 Feeding activity of *Atropacarus (Hoplophorella) chaliensis* , B. Burrow, FP. Faecal Pellets

PLATE 46

Laboratory Feeding of Oribatid Mite

Fig. 1 Feeding activity of *Atropacarus (Hoplophorella) reticulatus* B. burrow, FP. Faecal pellets

Fig. 2 Feeding activity of *Atropacarus (Hoplophorella) crenulus*

Fig. 3 Feeding activity of *Haplacarus xavieri*

Fig. 4 Holes produced by feeding activity of *Annectacarus malabaricus* FH feeding holes

Fig. 5 Faecal pellets produced by feeding activity of *Annectacarus mahabaeus*

Fig. 6 Feeding by larvae and adults of *Haplacarus davisi* and deposited egg, A adult, L larva, E egg, FP faecal pellets

PLATE 47

Laboratory Feeding of Oribatid Mites

Fig. 1 *Haplacarus porosus* feeding on leaf tissue FP faecal pellets

Fig. 2 Leaf skeletonised due to feeding by *Haplacarus davisi* LS. leaf skeleton

Fig. 3 *Heptacarus indicus* feeding on wood piece (W)

Fig. 4 Burrow produced in the wood due to feeding by *H. indicus* B burrow FP faecal Pellets

Fig. 5 Faecal pellets deposited by adults, tritonymph and larvae of *Meristacarus degradatus* A adult TN tritonymph L larva

Fig. 6 *M. degradatus* feeding on leaf tissue

Plate 48 - Feeding responses of oribatid mites to various food items provided

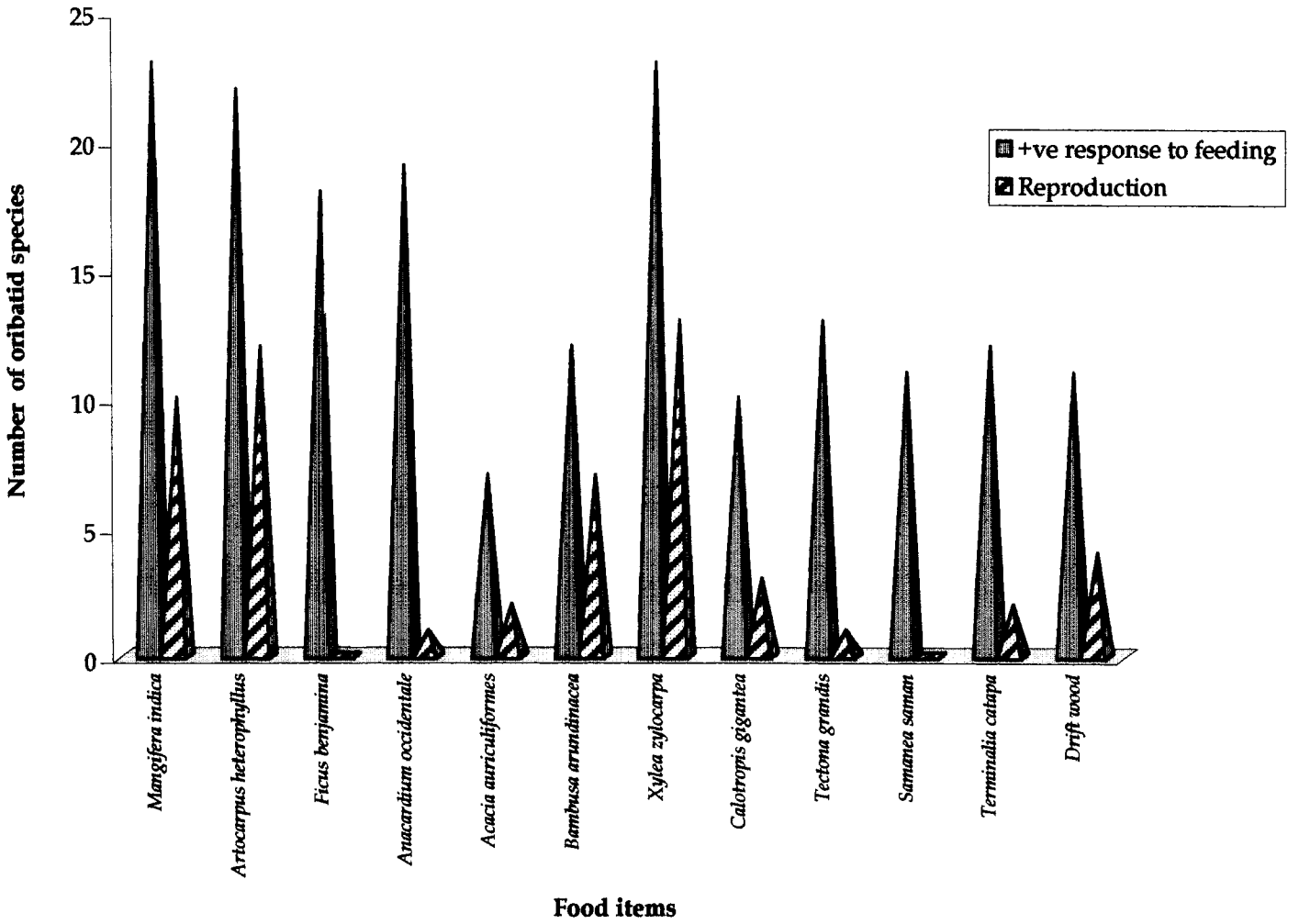


PLATE 49

Gnathal Appendages of Oribatid Mites

Fig. 1 Gnathal appendages of *Atropacarus (Hoplophorella) chaliensis*, C. chelicera, R. rutellum

Fig. 2 Gnathal appendages of *Phthircarus haqi*, C. chelicera

Fig. 3 Gnathal appendages of *Javacarus minutus* C. chelicera, R. rutellum, P. pedipalp

Fig. 4 Gnathal appendages of *Haplacarus davisi*, C. chelicera, R. rutellum, P. pedipalp

Fig. 5 Gnathal appendages of *Xylobates seminudus*, C. chelicera

Fig. 6 Gnathal appendages of *Pelokylla malabarica*, C. chelicera, R. rutellum, P. pedipalp

PLATE 50

Gnathal Appendages of Oribatid Mites

Fig. 1 Infracapitulum of *Cryptacarus dendrisetosus*

Fig. 2 Chelicera of *C. dendrisetosus*

Fig. 3 Infracapitulum of *Pelokylla malabarica*

Fig. 4 Chelicera of *P. malabarica*

Fig. 5 Pedipalp of *P. malabarica*

Fig. 6 Infracapitulum of *Apoplophora pantotrema*

Fig. 7 Chelicera of *A. pantotrema*

Fig. 8 Pedipalp of *A. pantotrema*

Fig. 9 Infracapitulum of *Allonothrus giganticus*

Fig. 10 Chelicera of *A. giganticus*

Fig. 11 Infracapitulum of *Archegozetes longisetosus*

Fig. 12 Chelicera of *A. longisetosus*

PLATE 50

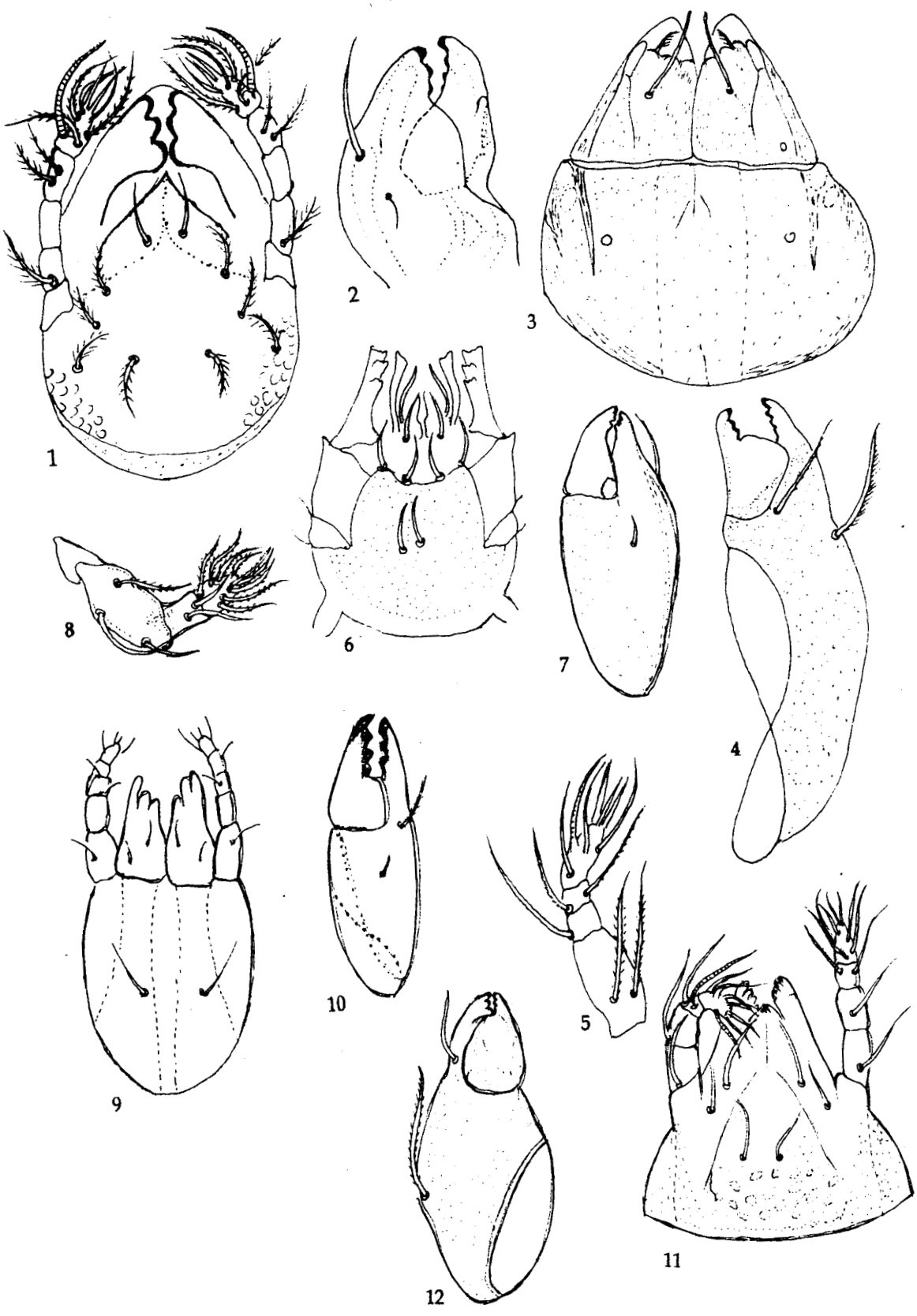


PLATE 51

Gnathal Appendages of Oribatid Mites

Fig. 1 Infracapitulum of *Scheloribates decarinatus*

Fig. 2 Chelicera of *S. decarinatus*

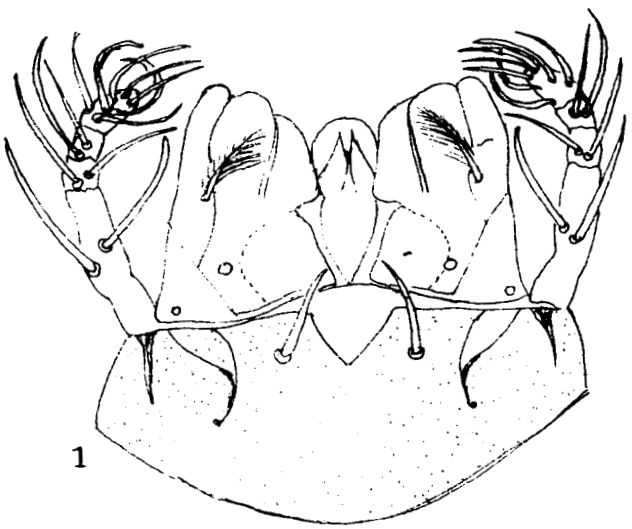
Fig. 3 Infracapitulum of *Xylobates seninudus*

Fig. 4 Chelicera of *X. seminudus*

Fig. 5 Infracapitulum of *Galumna flabellifera*

Fig. 6 Chelicera of *G. flabellifera*

PLATE 51



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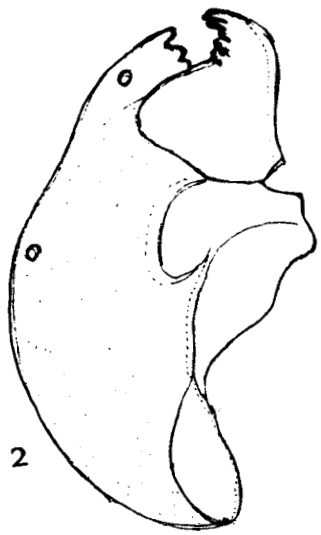

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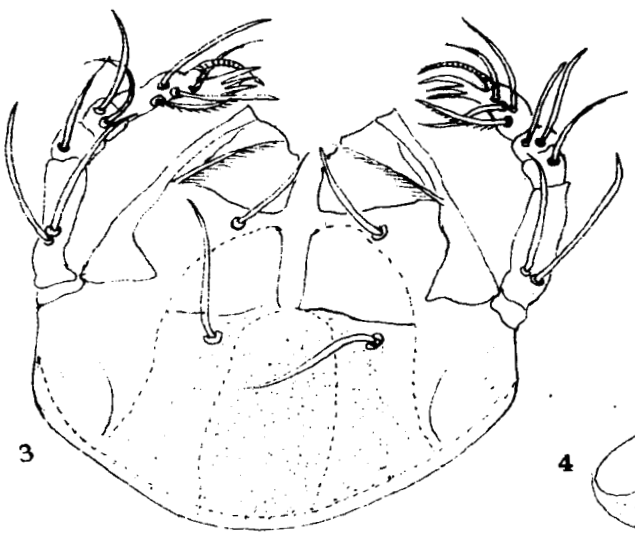

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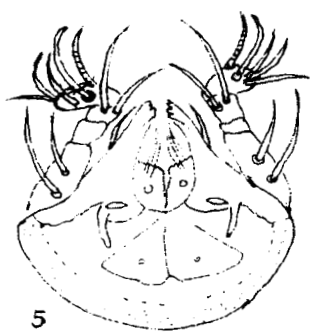

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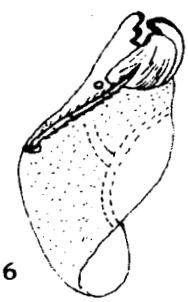


6

PART II
DISCUSSION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

DISCUSSION

Oribatid mites constitute the most conspicuous members of soil mesofauna. Their importance in natural ecosystems has been established beyond doubt by earlier investigators all over the world. (Schuster, 1956; Hartenstein, 1962; Luxton, 1972; Haq and Prabhoo, 1976; Behan and Hill, 1978, 1983; Haq, 1979, 1982, 1994, 1996; Kaneko and Salamanca, 1999; Heneghan *et al.*, 1999; Schuster *et al.*, 2000; Johnston, 2000; Ramani and Haq, 2001). As natural inputs, sufficient quantities of organic substances get gathered in every ecosystem of which plant litter constitutes the most important one. Decomposition of these substances and their subsequent incorporation into the soil are of utmost importance in all edaphic ecosystems. Integration of these plant materials into the soil ecosystem involves effective interaction of microbes and other soil microarthropods especially, the mites (Fujikawa, 1972; Dinsdale, 1974; Tadros, 1976; Hansen, 1999; Jain *et al*, 1999). Thus, mites bring about biodegradation of plant and other organic materials present in the soil. This activity of mites makes the soil rich in organic content, exerting a positive influence on soil fertility and agricultural productivity. This appears to be the direct effect of their food choice and feeding efficiency. Natural ecosystems offer an astounding diversity of food stuffs and this has led oribatid mites to develop a variety of behavioural and feeding responses. It is extremely difficult to categorise these responses in the field condition because of the amorphous condition of the soil and the microscopic nature of the mites. Therefore, any attempt to gather

information on this strategic point could be a better tribute to fertility restoration and agricultural productivity. Agriculture being the top most of human civilisation and its production rate marks the economic stability of a country, an indepth search has been designed through this work to bring about the hidden persuits of mite-litter interaction in soil. It is hoped that such a study would enlighten the strategies to be adopted for more agricultural production in future.

Results of the studies on the food habits through gut content analysis of 31 species of oribatid mites enabled to recognise three feeding categories, viz., macrophytophagy (feeding on higher plant materials), microphytophagy (feeding on lower plant materials) and panphytophagy, feeding on both lower and higher plant materials. Of the 31 species studied, 68% appeared to be macrophytopahges, 19% as panphytophages and the remaining 13% as microphytophages. This high incidence of macrophytophages in study sites permitted better interaction between macrophytophagous mites and the higher plant components. But this observation was contrary to that made by Behan and Hill (1978) who reported percentages of macrophytophages, panphytophages and microphytophages as 12, 50 and 32 respectively. Haq (1996) reported the percentage of occurrence of this as 37.33, 52 and 10.67 respectively. The above figures show that demarcation between different nutritional strategies is arbitrary than definite. The demarcation appears more obscure in between macrophytophagy and panphytophagy. This is evidenced by the wider food choice exhibited by the panphytophagous group. They could subsist on food items ranging

from bacteria, through lower plants to higher plants or even animal matter as was evidenced in the present study. Hence members of this group may show positive reaction to tests of any of the three nutritional categories at a time.

All the macrophytopahges in the present study turned out to be lower oribatids while panphytophages and microphytophages consisited of both lower and higher oribatid mites. Lower oribatid mites ingest large quantities of litter, and break it down mechanically through mastication. Their gnathal appendages especially the rutella and chelicerae were found equipped with broad and blunt cutting edges which assist them to triturate the plant residues. This makes them efficient feeders of higher plant elements as was evidenced among the members of Phthiracaridae and Lohmanniidae. A similar observation was made by Ramani and Haq (1990) who reported the feeding habits of *I. sellnicki* and *H. keralensis,* which they categorised as macrophytophages.

Membes of Phthiracaridae and Lohmanniidae though could be categorised as macrophytophages, exhibited pronounced differences in their food preferences. The phthiracarid mites viz., *A. (H.) crenulus, A. (H.) reticulatus, A. (H.) keralensis* and *P. haqi* consumed large quantities of woody elements. Accordingly, these mites could be assigned to 'xylophages' under the macrophytophagous category showing primary preference for woody ingredients of the litter. Another phthiracarid mite viz., *A. (H.) chaliensis* fed voraciously on roots of *C.gigantea.* This justifies their inclusion under rhizophagous macrophytophage. All the

lohmanniid mites studied with the exception of *H. indicus* specifically fed on leafy materials which indicated their phyllophagous nature. *H. indicus* resembled phthiracarid mites in their feeding preferences which actively devoured woody elements of *C. gigantea* and drift wood. This showed their xylophagous nature. The study thus enabled further categorisation of macrophytophages into xylophages, rhizophages and phyllophages. This would greatly help to assign macrophytophagous mites into their exact feeding slot for better utilization programmes.

Laboratory feeding experiments helped to understand the feeding behaviour of various groups of oribatid mites. The phthiracarid mites were seen tunnelling and boring into the wood pieces provided as food. Gradually, these tunnels were found getting packed with faecal pellets. Their immature stages, though very sluggish in nature, fed voraciously on the wood and carried 2-3 faecal pellets in their digestive tract. This could be easily seen through their transparent integument. These observations establish the fact that phthiracarid mites are primarily xylophagous in habit. Phthiracarid mites had been observed by earlier workers (Dinsdale, 1974; Haq, 1984, 1987; Haq and Konikkara, 1988; Edsberg and Hagvar, 1999) to bore into wood pieces forming tunnels. Thus, wood boring and tunnelling behaviour of this group of oribatid mites is a direct result of their xylophagous nature. Continued feeding deep into the wood culminated in the coalescence of tunnels leading to the final breakdown and decomposition of wood by these mites.

In the present study, traces of fungal hyphae were detected in the gut of immature stages of *A. (H.) reticulatus* but never in the adult. This

was a deviation from the macrophytophagous habit of phthiracarid mites. But in nature, fungal or bacterial growth is commonly seen in association with decaying higher plant materials. This in fact is an indispensible precursor for softening the highly complex materials before feeding. Hence it may not form a real food source in the case of organisms which feed on decaying plant litter. Therefore, this observation can be the result of accidental occurrence rather than compulsory and active feeding. Ramani and Haq (2001) reported a similar observation in the case of *Lohmannia* sp. They could recover fungal spores from the gut of this phyllophagous oribatid mite.

Laboratory feeding experiments revealed the various patterns by which lohmanniid mites attacked their preferred leafy food. *A. malabaricus, A. plumosus* and *A. mahabaeus* concentrated on the soft parenchymatous mesophyll tissue of leaf provided. The three species of *Haplacarus* viz. *H. porosus, H.xavieri* and *H. davisi* started feeding on soft tissue and subsequently attacked the more resistant veins. A similar trend of feeding was exhibited by *M. degradatus, C. dendrisetosus, P. elongatus, V. arboriformes* and *V. ramaniae* also. Cumulative effect of feeding by adults and immatures of several lohmanniid members thus led to the complete perforation of interveinal areas creating 'lochfrass' (Brauns, 1954) and 'Skelettfrass' (Dunger, 1964). Similar feeding reaction was reported in the case of other oribatid mites including Phthiracaridae by Riha (1951), Murphy (1953) and Schuster (1956).

Utilisation of leafy food by lohmanniid mites first started by attacking the soft mesophyll tissue. Later on, feeding proceeded to the

harder veinlets, gradually to veins and finally to the midribs. Thus, there is a progressive invasion and successful maceration of food types according to their stability. Such actions thus helped in skeletonising the leaves first and then their complete transformation into organically rich faecal pellets. This indicates the efficiency with which this group of mites can bring about break down of organic litter in natural ecosystems.

Another interesting aspect of lohmanniid feeding was its inclination to moist and partly decayed leafy food. In laboratory feeding experiments, the different lohmanniid members studied were found to reject dry leaves. This suggests the dependence of these species on moist litter for survival. It is possible that availability of moisture triggers microbial action on organic litter and such microbially conditioned litter is selected by these mites for feeding. This brings out the fact that oribatids can consume higher plant material only after an initial conditioning by microbial action where moisture is a pre-requisite. Such moistened litter requirement was reported for oribatid feeding by Hartenstein (1962) who established that strict leaf feeding mites preferred parenchymatous tissue of decaying leaves. Harding and Stuttard (1974) had also discussed the inability of microarthropods to utilise dry litter as food and Ramani and Haq (2001) noted the association of *Lohmannia* sp. and *H.rimosus* with moist litter accumulations.

Panphytophagous species like *A. longisetosus, A. giganticus, M. glabrus, X.seminudus, S. decarinatus* and *G. flabellifera* had a wider choice

of food including bacteria, fungi, leafy and woody elements and even animal matter. This type of feeding habit is ecologically of great advantage to the species possessing it. As a result of this eurytypic feeding habit, populations of a particular species may be able to survive in a number of widely differing habitats. (Luxton, 1972; Harding and Stuttard, 1974; Behan and Hill, 1978). Probably this would have been the reason for the high incidence of these species in most of the different sites studied.

Gut contents of 13% of mites revealed the presence of bacteria, fungal hyphae and spores and no trace of higher plant elements. These mites could thus be categorised as microphytophages in field conditions. The major gut constituent of *A. pantotrema* was bacteria and hence this species could be assigned to the status of 'bacteriophage' under microphytophagous category. Gut contents of *B. retiarius, O. kuhnelti* and *P. malabarica* revealed an abundance of fungal hyphae and spores. Hence these, three species were described as 'mycophages' under microphytophagous category. Bacteriophagy by oribatid mites had been reported earlier by Luxton (1972) and mycophagy by Luxton, (1972), Behan and Hill (1978, 1983), Neena and Haq (1992) Haq (1996) and Ramani and Haq(2001). This would endorse microbial involvement in the replenishment of colonies in several groups of higher oribatid mites.

The study thus revealed the presence of a variety of food items in various stages of digestion in the gut of the three different feeding categories of oribatid mites considered. This has great significance in

natural ecosystem where decomposition of accumulated plant litter forms a major aspect of nutrient cycling. Macrophytophagous oribatid mites through their feeding activities affect rates of litter decomposition through their role as secondary decomposers. Such action makes organic debris more suitable for attack by primary decomposers, namely the microflora (Luxton, 1979). Berthet (1967) estimated that 20% of the annual leaf fall in a wood land system in Belgium pass through the gut of macrophytophagous oribatid mites. On the other hand microphytopahagous species feeding on lower plant elements like fungal cushions , bacteria etc. helped in disseminating their spores in different soil layers. Effect of feeding by panphytophagous species appeared to be a combination of the above two as they assisted biodegradation by direct feeding on plant litter and indirectly by microbial activation. Thus they perform a dual role in food processing. Luxton (1972) noted panphytophages perhaps as twice active as macrophytophages in processing dead organic material. Therefore it can be concluded that combined activity of these three different feeding categories thus accelerated the decomposition rate of organic litter.

Considering the microscopic nature of oribatid mites, their contribution to organic decomposition appears insignificant when compared with that of annelids and other larger arthropods (Haq, 1994). But they have compensated this by their sheer abundance and extreme adaptability as was noticed in the current study. Wallwork (1976) reported that the density of cryptostigmatid mites was 176-410 x 10^3 in a hemlock mor. The high density of oribatid mites in various soil

ecosystems was noted by other workers also (Tadros, 1976; Haq and Ramani, 1991; Haq, 1994; Andre and Binche, 1998). Wallwork (1967) reported that in forest soils Cryptostigmata formed 75% of the total acarine fauna. This numerical abundance attains great significance in their contribution to total soil metabolism which is a direct result of their feeding activity. This clearly demonstrated the importance of oribatid mties in soil ecosystem as was also noted by earlier workers. (Wallwork, 1958, 1970; Luxton, 1972; Ramani and Haq, 1991; Haq, 1996).

The rate of food consumed by oribatid mites was found to depend upon several factors such as nutritional requirements, food processing and assimilatory ability and nutrient composition of the food item. In a detritus food chain, the nutritive value of its main components decreases in the order fungi>foliage materials> woody elements (Slansky and Scriber, 1985). Hence it follows that an organism which subsists on higher plant components should consume much more of its food than a mycophagous organism to get the same amount of nutrition. Moreover, the food processing and assimilatory efficiency of macrophytopahgous oribatid mites have been shown to be comparatively low, (Luxton, 1972). Hence, macrophytophagous oribatid mites should consume enormous amounts of food items of low nutrient value to meet their energy budget. From the stand point of biodegradation of organic litter, this appears to be very much advantageous as it involves direct utilization of woody elements and their final conversion into energy rich faecal pellets.

Release of faecal pellets by oribatid mites depended on the degree of feeding. Intense feeding led to the production of 2-3 faecal pellets per mite per day. For a microscopic organism of the size of oribatid mite, this was an appreciable event which indicated large amount of food consumption. As a result, a good quantity of food consumed was passed out in a semi digested state as was evidenced in the gut content and faecal pellet analysis. Quite often the surface of culture vessels in which mites were reared, were covered with faecal pellets. Large number of feeding holes and tunnels could be observed on the wood and leaf particles provided as food. These feeding sites were later found packed with heaps of faecal pellets. In field condition, these faecal pellets were found mixed with soil, accelerating microbial activity in the decomposition process. Availability of rain further enhanced leaching of nutrients from faecal pellets to soil. Thus oribatid mites help in energy flow from one trophic level to the next.

The phthiracarid mite, *A. (H.) chaliensis* collected from the roots and stem of *C. gigantea* growing in Chaliyam beach assumed significance because of their rhizophagous habit. Larval, nymphal and adult stages of the above mite bored and formed tunnels in the root by their preferential feeding activity. These tunnels were later found filled with faecal pellets formed as a result of trituration of these substances in their digestive tract. This tunnelling activity ultimately led to shredding of the entire mass, converting it into frass in their gut. This frass, on its egestion mixed easily with soil there by increasing soil porosity and nutrient content. Therefore, rhizophagous oribatid mites emerged as

better tools in the production of channels for aeration and drainage by clearing away the drying part of roots in the soil profile.

Laboratory feeding experiments brought to light another interesting fact. When oribatid mites were offered leafy/woody materials derived from different sources, the feeding response of individual species to each item was quite varied. Intense feeding was exhibited when the mite was offered leaf/wood collected from their original habitat. This was true in the case of both phyllophagous and xylophagous species. In certain cases, there was total rejection of the food while in other cases they resorted to feed on the food item offered to avoid starvation. But in such cases the feeding response was minimum and the number of faecal pellets produced was only 0-1 against the normal 2-3 as reported earlier. Above all, in such cases the mites never attained reproductive ability. On the contrary, when appropriate food was provided, intensive feeding followed by deposition of egg or spermatophore was noticed. This suggests ready availability of preferred food as a mandatory requirement in stimulating reproductive behaviour in oribatid mites as has been noted by earlier workers (Hartenstein, 1962; Shereef, 1971; Haq and Clement, 1981; Neena and Haq, 1991; Sumangala and Haq, 1991; Haq and Shereef, 1992; Ramani and Haq, 1993).

As currently noted, panphytophagous species, namely *G. flabellifera* could consume a variety of material as food, but could not reproduce on any of the items provided in the feeding experiments. Gut content analysis of this species showed the presence of large amounts of

fungal hyphae and spores which may be the result of active feeding of these items by the mite. However this species could not lay eggs or spermatophores in the laboratory cultures. It may probably follow that some other factor or factors in the environment is necessary to trigger reproductive behaviour in this species. This opens up new avenues for further research.

X. seminudus, although succeeded in reproduction on some of the food items provided, larvae and nymphs could not survive on those food items. Similarly in the case of most of the macrophytophages studied, the adults could survive by feeding on a number of food items, but the feedings of immatures did not match with that of the adults. They could consume only certain specific food items. A similar observation was made by Luxton (1972) who noted that in *Damaeus clavipes, Belba corynopus* and *Hypochthonius rufulus* there was considerable difference between immature and adult stages in their feeding habits under laboratory condition. Haq and Prabhoo (1976) reported that immatures of *A. longisetosus* fed on *Alternaria* which the adults rejected and adults fed on *Trichoderma* which the nymphs did not feed. These observations showed the extreme specificity and vulnerability of immature stages. In addition, this also points to a difference in the feeding habits between immature stages and the adults.

It was noted in the current study that nutritional requirements of immature stages were many times higher than that of the adults. This was well evidenced by the frequent availability of 3-4 faecal pellets in the digestive tract of immature stages in contrast to the normal 1-3 faecal

pellets or in some cases nonavailability of the same in adults. This is due to the fact that any growing organism has to ingest copious amounts of food to meet the high metabolic rate. In addition, population density of immatures quite often exceeded that of adults, especially in rainy season. The immature stages thus possessed several advantages over the adults when viewed in terms of their ability in litter decomposition. This is a positive aspect of biodegradation of organic litter by oribatid mites. This suggests the necessity for further research on the feeding strategies of immatures and their utilization for soil improvement.

The study also helped to understand a difference in feeding potential between various life stages. Deutonymphs and tritonymphs devoured much more food when compared to other stages. Most authors have agreed that immatures are the most important feeding stages and that they feed continuously (Wallwork, 1967; Woodring, 1963). However, feeding rates of different stages may not be constant throughout the life cycle and the tritonymph appears to be the stage which processes the maximum food material (Murphy and Jalil, 1964; Rockett and Woodring, 1966). Woodring (1963) further noted that young adults fed voraciously, but the amount of food consumed decreased with age. Berthet (1967) has shown that nymphal Cryptostigmata contribute as much as 70% of the total metabolism of the whole group during a year. Wallwork (1967) pointed out that the weakly chitinized immatures are more vulnerable to predation and may participate more than the adults in the transfer of material and energy to higher trophic levels in the community. This highlights the role of nymphal stages

especially deutonymph and tritonymph in the bioprocessing of organic litter through their voracious feeding.

In the present study, it was noted that oribatid mites, especially the micro and macrophytophages undertook active vertical and horizontal migration in soil. This activity of mites increased soil porosity and hence soil aeration. These migratory movements enabled the mites to come across with various microbial colonies in the soil layers. These microbial colonies which were quite often in a dormant or inactive state, got suddenly activated by the grazing activity of mites. During such action, the mites carried the fungal spores on their body setae and in the faecal pellets. When migrated to the surface of the soil covered with plant litter they dispersed these bacterial and fungal spores there, providing facility to invade the litter components initiating microbial action.

The macrophytophages on the contrary were sluggish and lethargic and did not undertake such large scale migrations. They restricted their movements within a limited area where their preferred food was available. This tendency can be attributed to their restricted distribution in several geographical zones.

An examination of the structural organisation of mouth parts in relation to functional significance in feeding revealed the influence of rutellae and chelicerae in the mastication of food materials. Pedipalp appeared to have a chemosensory function. The distal eupathidia of the palpal tarsus were involved in directing the food particles for mastication. The lateral lips guided the masticated food into the mouth

with the help of adoral setae. The general organisation of the gnathal structures remained the same in all oribatid members, but individual variations depending on the nature of food consumed was quite evident. The five members of the family Phthiracaridae viz., *A. (H.) reticulatus, A. (H.) crenulus, A. (H.) chaliensis, A. (H.) keralensis* and *P. haqi* included in the present study which constituted the most important xylophagous oribatids were unique, in having a concave vestibule on the rutella. Woolley (1967) reported that the concave dorsal surface or "vestibule" of the rutella behind the dentes as a feature associated with xylophagous mites. They possessed well pronounced and strong teeth as noticed by Dinsdale (1974). Active feeding involved the diversion of rutellae of both sides allowing the chelicerae to protrude between them one at a time. In the next stage, muscular activity retracts the chelicerae and rutellae on the wood particles, scraping it systematically using the stout, blunt dendites. These scraped food particles collected into the concave vestibule got further masticated by the chelicerae. The stenarthric infracapitulum with its highly reduced mentum allowed maximum rutellar mobility along lateral direction. Dinsdale (1974) noted that the rutella normally envelop the retracted chelicerae, but during feeding the chelicerae are protruded and the rutellae diverge as a result of the associated deformation of the infracapitulum. Grandjean (1957) also suggested that during the retraction of the chelicerae the rutellae converge to scrape their outer surfaces and the resulting particles are collected by the mouth. The study thus showed that this type of labiogenal articulation enabled these mites to triturate comparatively

large and stout wood pieces very effectively enforcing the maximum power of rutella.

The xylophagous lohmanniid mite, *H. indicus* also was characterised by the above type of gnathal appendages, but with a broader mentum. The chelicerae of this species were provided with well pronounced and strong teeth suited for devouring woody tissue as noted by Dinsdale (1974) and Haq (1982). All the remaining lohmanniid mites which were essentially phyllophagous resembled their xylophagous counter parts in possessing stenarthric infracapitulum, but with a broad mentum. This reduced rutellar mobility, so that rutellae could not be flexed to the same extent as that of the xylophagous species.This arrangement of gnathal appendages allowed certain amount of divergence of rutellae so as to accommodate large leaf pieces and even wood pieces. Leaf being soft and flexible compared to wood could be folded to suit the capacity of rutellar vestibule. These mites thus could feed efficiently on large leaf particles and even moderately sized wood pieces.

The microphytophagous species like *P. malabarica* had a diarthric type of labiogenal articulation with a more or less rectangular mentum. In this condition, the rutellar mobility towards lateral sides was highly restricted, allowing only small food particles to be accommodated between the rutellae. The chelicerae were elongated and narrow with small sharp teeth. This type of modification is suitable for nibbling fungal cushion and other smaller food items which at the same time resists them from consuming bigger food particles.

X. seminudus, a panphytophagous oribatid mite possessed an intermediate type of rutella and chelicera. The chelicerae of this species were strong and stout with well sclerotised chelae, and sharp and highly developed teeth. Even though diarthric condition existed, the well sclerotised rutellae were strong with stout denticles. The rutellar brush probably directed the food particles to the rutellar gap. This modified gnathal appendages were of high value to the species in utilising a wide range of food items including leafy and woody matter, fungal elements, spores, bacteria and even animal matter. This supported their consumption of food items of varying particle size.

A. gignaticus, another panphytophagous species was characterised by very long chelicerae with 3-4 teeth capable of triturating any type of food. *A. longisetosus* on the other hand possessed narrow rutellum with sharp teeth and chelicerae with less sclerotised chela and 2-3 blunt small teeth. This was not an adaptation for strict xylophagous or phyllophagous diet, but a combined compliment. Probably this would have helped the species to thrive equally well in all the sites studied where a variety of food elements were available. This possibly explains their cosmopolitan distribution.

M. glabrus and *S. decarinatus* possessed more or less similar type of gnathal structures with diarthric labiogenal articulation, broad well sclerotised rutellum, strong and thick chelicerae with 2-3 sharp teeth, a condition intermediate between macrophytophagous and microphytophagous type. *G. flabellifera* had well developed chelicerae with 3-4 blunt teeth. The two digits of chelicerae articulated in such a

way as to permit a high level of mobility. Rutellae were normal with 3-4 sharp dendites and rutellar brush. This modification of gnathal appendages helped them to devour a variety of food items.

The study thus showed that each group of oribatid mite was equipped with specific type of gnathal appendages which helped them in the feeding process. Xylophagous mites which excavated most of the food material possessed gnathal appendages that enabled effective trituration of large and hard wood pieces. In phyllophagous forms, gnathal appendages were organised in such a way that moderate sized leaf pieces could be held between rutellae for the masticatory action of chelicerae. Leaf being soft and flexible compared to wood, even larger pieces could be manipulated by rutellar action. In microphytophagous forms arrangement of gnathal appendages allowed only small particles to be held between rutellae. This helped effective handling of fungal hyphae, spores, bacteria etc. Panphytophagous species were characterised by an intermediate organisation of gnathal appendages between macrophytophagous and microphytophgous forms. This allowed them to utilise large and hard wood or leaf pieces as well as minute fungal hyphae, spores and bacteria. Pedipalp in all cases acted as the grasping organ, holding the food in position for the action of rutellum and chelicerae. Therefore modification of mouth parts in oribatid mites is well suited for the type of food preferred by the individual group.

PART II
REVIEW OF LITERATURE

Alphonsa Xavier "Bioprocessing of organic residues through oriculture technology " Thesis. Department of Zoology, University of Calicut, 2004

B. BREEDING BIOLOGY

REVIEW OF LITERATURE

Oribatid mites living in a variety of microhabitats are very often exposed to diverse environmental pressures. But they have successfully conquered the challenges offered by their habitat by adopting appropriate survival strategies. These survival strategies vary with species and within the species different developmental stages exhibit contrasting patterns of food choices and striking modes of reproductory manifestation. Here it is intended to make a consolidated account on the information available on the breeding biology of oribatid mites.

Biological studies of oribatid mites were initiated by Michael (1884, 1888). He reared species like *Damaeus nitens, Notaspis bipilis* and *Cepheus palmicinictum* in specially constructed culture cells made up of plastic rings mounted on microslides. He recorded duration of their development as 32, 60 and 345 days respectively. Almost for the next fifty years practically very little work was published relating to studies on the development of oribatid mites. Jacot (1933a) reported aparity, a phenomenon in which young individuals emerged out after the death of the mother in notaspid oribatids. In the following year, the same author (1934) studied life histories of some Havaiian oribatids by culturing them in the laboratory. Grandjean's (1933, 1939) classical studies on the changes occurring in the chaetotaxy of oribatids during the process of development appear to be a landmark in acarological research. Jacot

(1937) succeeded in rearing a few species of oribatid mites in special culture cells lined with Plaster of Paris and charcoal mixture.

Anantharaman (1944) showed that oribatid mites could act as vectors of cestode parasites. He studied the larval stages of *Moniezia expansa* and *M. benedini* in the vector oribatid mite, *S. madrasensis* by experimentally transmitting infective stages into the mite. Stunkard (1944) worked on the life cycle of a galumnoid mite, which could act as intermediate host of *M. expama,* at a constant temperature of 25^{0}C and relative humidity of 82%. A detailed study on the life span of three species of oribatids viz., *Scheloribates latipes, S. laevigatus* and *G. obvius,* which were found to act as vectors of anoplocephaline cestodes was conducted by Soldatova (1945). Strenzke (1949) reported viviparity among the members of the family Ameronothridae which were inhabitants of the marine littoral zone. Grandjean (1949) provided meticulous observation on the developmental pattern of the genital and anal plates of a few species of oribatid mites. His (1950, 1950a) subsequent works were of much interest to acarologists. He further provided data on the development of *Camisia segnis* and *Platynothrus peltifer.*

Taberly (1951) followed Grandjean's culture techniques while demonstrating parthenogenesis in *Trhypochthonius tectorum.* Van Der Hammen (1952) gave an illustrated description of the deutonymph of *Fuscozetes fuscipes* along with morphology of the immature forms of four common species: Pauly (1952) observed the process of spermatophore deposition in oribatids and proposed this as the chief mechanism of

sperm transfer in this group of mites. Cleat (1952) briefly described the postembryonic development of *S. laevigatus* by culturing them in slender dishes. Taberly (1953) worked out the postembryonic development of *Trhypochthonius tectorum*. Van Der Hammen (1954) described the various life history stages of *A. magna* and *A. schuilingi* including the chaetotaxy. Grandjean (1954) proposed a phylogenetic system of classification for families based on comparative development of oribatids. Sengbusch (1954) modified culture techniques for rearing free living mites and studied the developmental pattern of three oribatid species viz., *G. nervosa, G. elimatus,* and *G. longipluma*. Rhode (1955) constructed culture vials using a mixture of plaster of Paris and charcoal in dram vials for rearing oribatid mites. During the subsequent year (1956) he published a paper giving details of further improvement in the rearing of small arthropods including oribatid mites. Pauly (1956) gave information on the biology of three species of oribatid mites viz., *Belba geniculosa, B. gracilipes,* and *B. clavipes*. The author reported that the first species completed its development in 150 days while the latter two took only 75 days. Spermatophore deposition in these species was also studied by him. Copulation, which is a very rare phenomenon among oribatid mites was reported for the first time by Grandjean (1956). Taberly (1957) described deposition of spermatophores by males and picking up of the same by females in a few oribatid mites. He discussed the structural peculiarities of the spermatophores also. Sengbusch (1958, 1958a) traced the developmental stages of eight species of oribatid mites and described

in detail the development of *N. nana*. Sitnikova (1959) gave details of the life cycle of *B. boreus* by culturing it on leaves and potatoes.

Wallwork (1960) studied the behaviour of oribatid mites form West Africa and North America and concluded that West African species had an upper critical and lethal temperature. Sengbusch (1961) described spermatophores and sperm transfer in oribatid mites. The biology of three orbatid species viz., *C. cisalpinus, S. laevigatus* and *O. neerlandica* was studied by Woodring and Cook (1962) who provided description of all stages. Hartenstein (1962a) traced the life history of *B. kingi* in the laboratory at 20^{0}C and traced development on a diet of *Trichoderma leonium*. He (1962b) studied the development, biology and ecology of *Metabelba montana* and *Eremobelba nervosa* . The influence of temperature on development of *C. gracilis* and mechanism of oviposition was dealt in detail by the same author (1962c). Further studies by him (1962d) showed that eggs of *Platynothrus peltifer* developed into adults within five months. While investigating the association of *Protoribates lophotrichus*, the above author (1962e) reported that the females deposited eggs on decaying parenchymatous leaf tissue rich in living microorganisms. The emergent larvae consumed these microorganisms as food. The period of development from egg to adult was shown to be approximately five months. He (1962f) gave an account of the immature stages of *S. diaphanum* and their role in the decomposition of conifer needles. Bhattacharya (1962) through his studies on feeding experiments concluded that the average longevity was an indication of the nutritive

value of food. The occurrence of copulation in oribatid mites was confirmed by Schuster (1962).

The nutritional and reproductive aspects of oribatid mites were reviewed by Woodring (1963). He gave a consolidated list of oribatids which could be successfully cultured in the laboratory. Sengbusch (1963) discussed the mechanism of maintaining a higher relative humidity in culture vials for rearing oribatid mites. Studies conducted by Lebrun (1964) on the development of oribatid mites established the fact that higher oribatids could complete their development faster than primitive oribatids. Through their observations on the biology of the oribatid genus *Tectocepheus,* Murphy and Jalil (1964) estimated the actual number of annual generations completed by this mite.

Studies conducted by Block (1965) gave detailed information on the life histories of *Platynothrus peltifer* and *Damaeus clavipus.* His examination of the immature stages of the above species showed that both species had a single annual generation. Based on his field and laboratory observations, Jalil (1965) furnished a detailed description of the life cyle of *Hermannia scabra* and illustrated its immature stages. Madge (1965) investigated sensory physiology and behaviour of *B. geniculosa* and worked out its thermal death point. Woodring (1965) reared five species of oribatid mites viz., *G. confusa, G. parva, R. flavus , S. parabilis* and *S. nudus* under laboratory conditions and presented a report on their development.

Block (1966) noticed seasonal fluctuation in the population density of oribatid mites which he correlated with their reproductive cycles.

Rockett and Woodring (1966) studied the biology of *Pergalumna omniphagus* and *C. jewelli* in relation to temperature changes which influenced the metabolic rate, ovarian development and egg production. Lions (1967) provided an illustrated description of the prelarva of the primitive oribatid mite, *R. ardua*. Cancela Da Fonseca (1969) provided information on the biology of *D. quadrihastatus*. Arlian and Woolley (1969) suggested that life stages of *Liacarus cidarus* represented a typical pattern in oribatid mites. He could identify immature stages by the number of genital disc suckers. They also described notogastral segmentation and developmental chaetotaxy. Based on his studies on the ecology and biology of *N. palustris*, Lebrun (1969) suggested that smaller species could complete their life cycle faster than larger species. Webb (1969) measured O_2 consumption in *N. silvestris* at 10^{0}C. His study revealed that larvae had relatively low respiratory rate, while in protonymph the case was high.

Lebrun (1970) reported that temperature, availability of food, light etc. exerted a profound influence on the developmental period of *N.palustris*. Arlian and Woolley (1970) studied the biology of *L. cidarus* by rearing it on a diet of the *Cladosporium* mould and reported that its life cycle consisted of five active instars. Woodring (1970) gave a comparative account on the homology and function of the male and female reproductive systems of thirty species of oribatid mites belonging to twenty two families. Woolley *et al.*, (1970) studied the biology of *L. cidarus*. Baulmer (1970) studied morphology, biology and ecology of *H. gibba*. He noticed that oviposition in this species occurred during the

driest period of the year. Sengbusch and Sengbusch (1970) traced the life history of *O.nitens* at a temperature of 20°C. Trave (1970) presented a detailed description of the immature stages of *Neoribates* sp.

The waterhyacinth mite, *O. terebrantis* was studied by Perkins (1971). His studies showed that the mite completed its development from egg to adult in about ten days. Shereef (1971) provided information on life cycle of five species of oribatids viz., *Granuloppia* sp. *B. meridionalis, E.geographica, Spatiodamaeus subverticillipes* and *Paleacarus kamanaskii* by rearing them on a diet of the fungus, *Aspergillus flavus*. He further described the production of spermatophores and their morphology. The same author (1971a) carried out comparative studies on the life cycle of oribatid mites from USSR. While reviewing the bioecology of edaphic collembola and acarina, Butcher *et al.* (1971) discussed the embryonic development and spermatophore deposition in different species of oribatid mites. Morphological details of all the nymphal stages of *Eremaeus cordiformis* collected from soils of France were described by Lions (1971). Sitnikova (1971) studied postembryonic development of *Eupelops torulosus* by culturing the mite under laboratory conditions.

Seniczak (1972) devised a culture cell with asbestos bottom for culturing oribatid mites in the laboratory. Jalil (1972) studied development of *Platynothrus peltifer* from USA at a constant temperature of 25°C. Shereef (1972) cultured oribatid mites on the fungi, *Penicillium martensii* and *A.flavus*. He found that the duration of life cycles varied considerably and in the case of species producing males, duration of the male life cycle was shorter than that of the female. He noticed that *P.*

kamanaskii reproduced parthenogenetically. Salvatore and Alfredo (1973) recorded the duration of life cycle of *O. concolor* and *Epidamaeus* sp. The occurrence of prelarva in *Plesiodamaeus craterifer, Zetorchestes falzonii, Mycobates parmeliae, Dometorina plantivaga plantivaga. Epilohmannia* sp. and *Sphaerozetes* sp. was reported by Lions (1973)

Cancela Da Fonseca (1975) provided information regarding spermatophore deposition and some trophic aspects of *D. verticillipes. H.gibba* and *S. magnus*. Metz and Sharma (1975) while reporting a new species of oribatid mite, *O. durhamensis* gave complete picture of its biology also. The pattern of oviposition in *O. terebrantis* was studied by Cordo and De Loach (1975). They noticed that gravid females cut round holes of 0.1mm diameter with their mouth parts and inserted the egg deep into the aerenchyma cells of the host. Luxton (1975) carried out calorimetric studies of oribatid tissue and expressed it in terms of life histories and metabolic rates. Seniczak (1975) described morphology and biology of three species of *Oppia* viz., *O. subpectinata, O. bicarinata* and *O. neerlandica*. Weigmann (1975) worked out the life cycles of *H. subglabra, P. peltifer* and *Ameronothrus schneideri* by conducting laboratory and field studies.

Cordo and De Loach (1976) described the biology of waterhyacinth mite, *O. terebrantis* providing data on the behaviour of immatures and adults. Sankaran (1976) suggested that the above mite could be effectively used in the control of waterhyacinth. Shereef (1976) reared *O. sticta* and *Multioppia wilsoni* on their preferred food, *A. flavus,* to study their postembryonic development. His studies showed that the

males completed life cycle in 11-18 days while females took 16-21 days. His (1976a) subsequent work on the life history of two lohmanniid mites viz., *P. aciculatus* and *L. aegypticus* showed that they took 71 and 101 days respectively for completing development when reared on rotten wood, decaying roots and dry leaves. A detailed description of the morphology of all the life stages was also provided by him.

The structural peculiarities of the ovipositor and the mechanism of oviposiiton in the oribatid mite, *Machadobelba symmetrica* were studied by Wallwork (1977). Suzuki (1977) described the immature stages of the lohmanniid mite, *Perlohmannia gigantica.* Shereef (1977) studied life cycle of *Plakoribates multicuspidus* and *Xylobates souchnaiensis* giving illustrations of all developmental stages. Webb (1977) described the general biology and life cycle of *S. magnus* and reported that the time taken for development from egg to adult was 400 days. Mitchel (1977) gave brief review of the existing data on the oribatid life histories and related the information to their physical and biological environment.

Haq (1978) gave the details of postembryonic development of *A. longisetosus* and *L. ornatissimus* which took 50 and 176 days respectively for completing their life histories. Bhattacharya *et al.* (1978) reared *O. nodosa* at different temperatures which induced changes in the total duration of development and showed that it caused dormancy when the temperature was brought down to 8°C. An extensive study on the immature stages including the prelarva of *Carabodes willmanni* was undertaken by Bellido (1978) who gave emphasis to chaetotaxic features. A detailed description of the morphology of the immature forms of *A.*

coleoptrata, A nitens and *Parachipteria willmanni* was provided by Seniczack (1978). He discussed the development of setation in these mites. Norton *et al.* (1978) described morphological features of the immature stages of *Epilohmanniodes terrae.* Haq (1979) studied the postembryonic development of *G. flabellifera orientalis* from Kerala. He reported that the mite took an average of 25 days to complete its development at a temperature of 31±1°C. Travenicek (1979) presented information on the factors influencing spermatophore deposition and sperm transfer in oribatid mites through his studies on nine species of liacarid mites.

Haq and Clement (1980) made a comparative analysis on the duration of development of a few species of oribatid mites representing primitive and higher forms viz., *L. ornatissimus, A. longisetosus. G.flabellifera orientatlis* and *G. longipluma.* Seniczak (1980) selected two species of the genus *Trichoribates* viz., *T. trimaculatus* and *T. novus* and described the morphology of their immature stages. The same author (1980a) studied and compared the immature stages of *Scheloribates latipes* with that of *S. laevigatus* and found that the two species mainly differed in the shape of setae on notogaster. The work of Shereef and Zaher (1980) provided information on the morphology and biology of an Egyptian oribatid mite viz., *O. bayoumi.*

Fernandez (1981) described the spermatophores of *Epilohmannia maurii* with the help of photographs. Haq and Clement (1981) provided information on the spermatophores and their transfer in *P. malabarica.* They also studied the influence of preferred food, moisture content and

presence of female on spermatophore deposition by the males. Andre and Voegtlin (1981) studied the developmental biology of *C. carolli* collected from soils of Belgium. Luxton (1981) briefly described the field population, developmental biology, vertical distribution and seasonal variation in the population density of oribatid mites. Based on his observations on the feeding habits of ten species of oribatid mites, Haq (1982) concluded that rate of reproduction is enhanced by preferred food. West (1982) traced the life history of three species of subantarctic oribatid mites. The process of spermatogenesis in *H. gibba* was studied by Waitzbauer (1983).

Clement and Haq (1984) reported in detail the feeding and breeding biology of *P. malabarica,* which took an average of 18.2 days at a temperature of 30 $\pm$ 1°C to complete its development from egg to adult. The postembryonic development of an oribatid mite, *Paralamellobates bengalensis* inhabiting the leaves of *Dioscorea alata* was observed at a temperature of 20$\pm$1°C and a relative humidity of 80% by Haq and Ramani (1984) who reported the average duration as 26.7 days. Nannelli and Bernini (1984) studied postembryonic development of *C.pegazzanoae* along with its morophological and ecological aspects. They suggested that young oribatid mites were more similar to one another than to their respective adults. Harding and Easton (1984) studied the development of two species of phthiracarid mites viz., *S. magnus* and *P. anonymum.* Haq (1984) observed that *H. hirsutus* bored tunnels in the wood which provided a favourable microhabitat for oviposition and physical protection for immature stages.

Gourbiere *et al.* (1985) described life history of *Adoristes ovatus* in *Albie alba* needles and reported that growth from egg to adult required one or two years. In order to simulate natural conditions, Schatz (1985) created fluctuating temperature in the laboratory to rear *Oromurcia sudetica* and observed similarities in results of both laboratory and field studies. Temperature tolerance of an alpine oribatid speicies viz., *Epidamaeus diversipillus* was worked out by Schenker (1985) who reported that the species completed its life cycle within 119±6.8 days at a temperature of 29°C. Haq and Ramani (1987) observed that the females of *P. longiporosus* laid solitary eggs inside the aerenchyma cells of waterhyacinth leaves. Larval and nymphal stages lived in tunnels. Biology of *P. insignis* was studied by Fujikawa (1987) who found that there was an increase in the proportion of gravid females in the culture. Haq (1987) observed that bacterial colonies obtained from faeces of different immature stages of *H. hirsutus* varied considerably. Ramani and Haq (1987) carried out biological studies of *S. decarinatus,* which was a common inhabitant of the terrestrial weed *C. odorata*. The same authors (1987a) studied the effect of temperature on the duration of development of this species. They reported that the total duration of development from egg to adult was on an average 29 days at a temperature of 31±1°C.

Fujikawa (1988) studied the biology of *O. nova* and found that almost all specimens collected were females. The same author (1988a) reported that *T. velatus* and *T. cuspidentatus* showed higher ability of reproduction when plant litter and humus from forest floor were used as manure in fields. Norton (1988) found larvae of two undescribed species

of mite genus *Leptus* attached to the heavily sclerotised cuticle of ten species of oribatid mites. Norton *et al.*, (1988) provided information on the feeding biology, population ecology and occurrence of parthenogenesis in *M. nasilis*. The morphology of immature stages of two species of moss mites viz., *E. torulosus* and *E. occultus* was discussed by Seniczak (1988). The same author along with Salhoy (1988) described the immature stages of *Chamobates cuspidatus* and *C. schutzi*. Ramani and Haq (1988) undertook biological studies of *Uracrobates indicus* harbouring the leaves of *Mangifera indica* and showed that the mite could complete seven to eight generations per year if reared in laboratory. Taberly's (1988) studies on the influence of temperature on the life cycle and development of *P. peltifer* established a supraoptimal threshold in this species.

The reproductive pattern and duration of life cycle of four species of oribatids viz., *Eohydroppia magnus, Ischeloribates lanceolatus, Quadroppia quadricarinata* and *Archoplophora villosa* were studied by Kaneko (1989). Alberti *et al.*, (1989) provided a summary of the available data on spermatophore structure among oribatid mites using light and electron microscopic studies. Seniczak (1989) described the morphology of immature stages of moss mites, *Melanozetes mollicomus* and *M. meridianus*. The same author (1989a) illustrated the morphology of immature stages of *Fuscozetes fuscipes* and *F. setosus*. Haq (1989) while discussing some interesting aspects of oribatid behaviour, explained the various unusual reproductive strategies like aparity, viviparity, parthenogenesis and aggregation of immature stages in these species.

Norton (1990) made an elaborate study on various aspects of oribatid mites namely taxonomy, biology and ecology. Seniczak (1990) studied the immmature stages of two species of moss mites viz., *Liebstadia similis* and *L. humerata*. Sumangala and Haq (1990) reported the ovipositional behaviour of *G. cuneata* and *G. alata*. The authors found that both species laid large numbers of eggs which were found glued together with a sticky material.

Haq *et al.*, (1991) reported ovoviviparity in *S. fijiensis*. The influence of a few species of fungi on the postembryonic development of *O. kuhnelti* was studied in the laboratory at a temperataure of 30±2°C and a relative humidity of 82-85% by Neena and Haq (1991). They reported that the mite completed its life cycle in 14.15 to 16.70 days on their preferred food of *Penicillium*. Norton and Palmer (1991) studied the distribution mechanism and evolutionary significance of parthenogenesis in oribatid mites. Dennis *et al.* (1991) concentrated their studies on mite-plant association from the Eocene of Southern Australia. Sumangala and Haq (1991) reported that *G. cuneata* took 58-60 days to complete its life cycle when fed on *E. crassipes*, while it required only 39-44 days when fed on fungal diet. Lebrun *et al.* (1991) described the various life history strategies exhibited by oribatid mites.

Haq and Shereef (1992) studied postembryonic development of a species of *Galumna* in the laboratory at a mean temperature of 28°C and a relative humidity of 80% providing different species of fungi as food. They found that the mite completed the life cycle in an average of 34.3 days on the preferred food, *C. geniculata*. Palmer and Norton (1992)

observed that the oribatid mite taxon *Desmonomata* reproduced by thelytokous parthenogenesis and noted males as non-functional. Shereef and Haq (1992) worked out the biology of *G. triquetra*, an oribatid vector of cestode parasites of domesticated animals, at a temperature of 27±1°C and a relative humidity of 85% by offering the preferred food *Curvularia geniculata*. They found that the mite completed its development in about 34.1 days. Sumangala and Haq (1992) observed different stages of development of *O. terebrantis* in a single leaf of *E. crassipes*. Ramani and Haq (1993) studied the influence of food on the development of *Allonothrus giganticus*. The authors found that the mite completed its development in 30-32 days on yeast while it took 42-46 days when partly decomposed wood was given as food. Norton *et al.* (1993) described the various reproductive modes exhibited by oribatid mites.

Wrensch *et al.* (1994) suggested that holokinetic chromosomes and inverted meiosis enabled arrhenotoky and parahaploidy in oribatid mites. Smrz (1994) studied some aspects of life history of oribatid mites under conditions of extreme humidity combined with microorganisms. Sumangala and Haq (1995 & 1995a) studied in detail the reproductive strategies of *O. terebrantis*. They found that the mite took 21-23 days for completing its development. Block and Convey (1995) worked out the biology, life cycle and ecophysiology of the Antarctic mite, *Alaskozetes antarcticus*. Succession of litter population by oribatids in different forest types was studied by Irmler and Pfadenhauer (1996). Marie *et al.* (1997) examined the phenomenon of obligate thelytoky in oribatid mites who recommended an alternative hypothesis for the inducement of thelytoky.

The authors further studied its relevance to the observed diversification of thelytokous oribatid mites.

Pinto *et al.* (1998) artificially infected oribatid mite species *Lamellobates pallustris, S. praencisus rotundiclava, P. decoratissima* and *Galumna* sp. with eggs of *Anaplocephala magna, A. perfoliata* and *Anoplocephaloides mamillana* and worked out the duration of infection in different species of mites. Weigmann (1998) studied segmentation of oribatid mites during development. Behan and Paoletti (1999) gave a detailed description of general ecology, biology and life history of oribatid mites. They suggested that oribatid mites with low metabolic rate, slow development and low fecundity cannot respond rapidly to resource scarcity. Haq (1999) studied the development of oribatid mite vectors by offering them cestode eggs as food. Fernandez (1999) described the tritonymph and adult stages of the oribatid mite *Oripoda benegasi*. Edsberg (1999) reported that oribatid mites *S. striculus, R. ardua* and *A. ovatus* develop inside decomposing spruce needles. Schuster *et al.* (2000) artificially infected 6 species of adult oribatid mites and 2 immature stages with eggs of *M. expansa* with success in the case of adults. Kuriki (2000) studied life histories of oribatid mites in sphagnum mines. Sexuality and asexuality in oribatid mites were studied on a molecular basis by Maraun (2001). The same author (2001 a) through a study on sexual and parthenogenetic oribatid mites derived evolutionary and phylogenetic conclusions. Smrz (2002) described microanatomical and microbiological characteristics of the quiescent state of an oribatid mite, *Scutovertex minutus*.

PART II
MATERIALS AND METHODS

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

MATERIALS AND METHODS

1. Selection and Extraction of Mites

In the present work, developmental biology of a few selected members of oribatid mites which were proved to be important in biodegradation of organic litter were carried out. After a careful scrutiny of the results obtained through gut content analysis and laboratory feeding experiments, three members viz., *A. (H.) chaliensis, H. indicus* and *H. davisi* were selected for detailed study. The first two species were xylophagous while the third species was a phyllophage *A. (H.) chaliensis* and *H. indicus* were collected from drift wood and decaying roots of *C. gigantea* from the study site, CB. *H. davisi* was collected from the litter sample below the tree *X. zylocarpa* from the site KS. These mites were extracted in live condition using modified Berlese - Tullgren funnel apparatus and were reared in individual culture vessels.

2. Rearing of Mites

About 30-50 mites comprising adult males and females were introduced into each culture vessel. Appropriate food was then placed in the centre of each culture vessel. Partly decaying root pieces of *C. gigantea* were introduced into culture vessels containing *A. (H.) chaliensis* as food. *H.indicus* was reared on pieces of drift wood. Semi-decomposed leaves of *X. zylocarpa* were provided as food for *H. davisi.* After introducing the mites and the respective food, the culture vessels were closed with lids containing minute holes for exchange of gases. Culture vessels were

properly labelled and then left undisturbed (Plate-44, Fig. 1). Extreme care was taken to maintain optimum hygienic conditions by checking the culture twice daily. The daily cleaning operation consisted of replenishing the food, addition of water if necessary, preventing fungal attack, careful removal of accumulated wastes etc. The culture vessels were kept in desiccators and maintained at a relative humidity of 80-90% and temperature of 30± 1°C during the entire period of investigation.

3. Study of Life Stages of Oribatid Mites

Culture vessels were routinely examined to study the biology of each species. Surface of culture medium and food materials were checked regularly to see whether the females had oviposited. Ovipositional behaviour of females in each case was noted. When eggs were detected, they were transferred into separate culture vessels with maximum care. A minimum of 10 eggs were introduced into each culture vessel. Further development of the eggs were followed closely. A detailed study of the egg, incubation, hatching, larval and nymphal stages, intervening quiescent and moulting phases was carried out. Appropriate photographs were taken as and when necessary. Permanent slides of the various life stages of each species were prepared. Mounted slides were then examined under a Leitz Aristoplan microscope to study the morphological details. Drawings were made using the camera lucida attached with the microscope. Measurements were taken using an ocular micrometer. Details regarding the duration of development from egg to adult including the duration of each individual stages were worked out.

PART II
OBSERVATION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

OBSERVATION

Oribatid mites which comprise the most abundant group of soil inhabiting arthropods, exert significant influence in the humification process, soil fertility and nutrient cycling. Sampling of these mites from various ecosystems very often revealed the presence of sufficient number of immature stages, particularly during rainy seasons. Laboratory observations on the feeding habits of these stages show that their feeding potential is far greater than the adults. This clearly signifies their importance in energy flow. Though some information is available on the breeding habits of higher oribatid mites, our knowledge on their biology, particularly of primitive oribatid mites is very much meagre. Therefore, three species of oribatid mites, viz., *A.* (*H.*) *chaliensis*, *H. davisi* and *H. indicus*, which were proved to be actively involved in bioprocessing of organic litter in the feeding biology section were reared in the laboratory by offering their preferred food. The three species of mites selected belonged to the macrophytophagous category.

1. Postembryonic development of *Atropacarus (Hoplophorella) chaliensis sp. nov.*

A. (*H.*) *chaliensis* was recognised as one of the most abundant species of oribatid mites inhabiting the decaying wood and root of *C. gigantea* growing in Chaliyam Beach.

Oviposition

Adult females oviposited inside the wood. The eggs were inserted into the root tissue of *C. gigantea* in small depressions. The eggs were solitary and never found in clusters but always within a small area (Plate: 53 Fig.2).

Incubation and Hatching

Incubation period ranged from 4-5 days. On the third day of incubation tiny, black patch appeared within the egg shell. This patch darkened and became prominent afterwards (Plate- 53, Fig.1). Later the egg split along this patch, releasing the larva.

Duration of life stages (Table 10)

Soon after hatching, the larvae (Plate-53, Fig.3) remained immobile for about two hours and afterwards showed the signs of feeding and remained concealed within the wood piece. The larvae excavated the wood during their feeding activity. The active period of larva took on an average of 11.3 days. The physical activities of the larvae became restricted towards the end of this period. The larvae gradually became inactive, swollen in appearance, sluggish in habit and stopped feeding activities. Then they became immobile initiating the first quiescent phase. 3-4 days of quiescent phase got terminated by the process of moulting which lasted 2-3 hours. At the beginning of this process, a vertical slit appeared on the notogaster which increased in size. After about 15-30 minutes, the prodorsum came out. Up and down movements of the body resulted in the casting off of the exuvium. Newly moulted nymph remained stationary for some time near the

exuvium, after that it moved away in search of food. The protnymph (Plate- 53, Fig. 3) continued to be active for about 14-15 days and then entered the second quiescent phase which lasted for 3-4 days. Moulting of the second quiescent phase released the deutonymph (Plate-53, Figs. 4&5). These nymphs excavated the wood during their feeding activity which resulted in the formation of irregular tunnels within the wood. The existence of the nymph could be easily distinguished by the faecal pellets produced by them especially around the tunnels. The active period of deutonymph ranged from 17-18 days after which it became quiescent. The third quiescent phase extended to 4-5 days and terminated by the emergence of tritonymph (Plate-53, Figs. 4&5). The tritonymph had an active existence of 19-20 days, at the end of which it entered into the fourth quiescent phase. This lasted for 6-7 days allowing the emergence of adult. The newly moulted adults appeared pale yellow in colour with a light pinkish tinge. The colour changed to wheat yellow on the fourth or fifth day of emergence. Adults often wandered outside the wood tunnels where as immatures remained inside.

The results of the study indicated that the development of *A. (H.) chaliensis* from egg to adult could be completed with in 81-89 days (Table 10).

Morphological description of life stages of
Atropacarus (Hoplophorella) chaliensis sp. nov.
(All measurements given in μm)

Egg

Measurements (Table 11): Length: 180 (Range 175-184)
Width : 162 (Range 157-165)

Freshly laid egg appeared whitish in colour with a blue tinge and oval in shape with one end slightly conical. Though smooth and shiny in appearance, when viewed under higher magnification, the surface of the egg exhibited striations which ran longitudinally from one end to the other.

Larva [Plate-52, Fig. 1]

Measurements (Table 11): Length: 315 (Range 310-318)
Width : 165 (Range 160-169)

Larva appeared small and fragile. Shape globular. Body white in colour and almost transparent. Larvae remained within the root in tunnels produced by the feeding activity. It moved very slowly with its three pairs of legs.

Prodorsum (Plate-52, Fig . 1)

Prodorsum triangular and aspis indistinct. Lateral carina poorly developed. Three pairs of prodorsal setae present. Seta *ro* short, blunt, smooth and curved anteriorward, inserted far below the anterior margin of the rostrum, measuring 14. Seta *le* with barbs towards the tip and measuring 37. Seta *in* minute inserted above the level of *bo*. Bothridium cup shaped with lateral opening. Sensillus short with dilated tip. Prodorsal integument with wrinkles.

Notogaster (Plate- 52, Fig. 1)

Notogaster globular with convex margin. Its connection with aspis marked by a deep notch. Five pairs of notogastral setae viz., c_1, d_1, e_1, f_1 and ps_1 (Table 12). All these setae smooth with pointed tip and

deeply inserted into the integument. Setae show variation in length. Integument of notogaster with wrinkles.

Ventral Region (Plate- 52, Fig. 1)

Rutellum and chelicera well developed, but without scelrotisation. Infracapitulum with three pairs of setae, *a, h,* and *m*. All these setae smooth and thin. Pedipalp three segmented. Epimeral boundaries indistinct. Epimeral setal formula 1-0-1-0. Seta on epimere 1 long. All setae smooth. Genital area not developed (Table 13). Anoadanal plate rectangular. Each plate bears two pairs of smooth, short anal setae at its inner margin and two pairs of adanal setae away from the inner margin (Table 14). Both these setae smooth with pointed tip. Integument of ventral region wrinkled.

Legs

Three pairs. All legs monodactylous

Protonymph [Plate- 52, Fig. 2]

Measurements (Table 11): Length: 385 (Range 380-398)
Width : 200 (Range 195-206)

Protonymph could be easily distinguished from the larva by its larger body size and possession of four pairs of legs. Body pale white in colour and oval in shape. Occasionally, it came out of its feeding tunnel and wandered among the food. It fed voraciously boring tunnels into the wood while feeding.

Prodorsum (Plate-52, Fig. 2)

Prodorsum more distinct than that of the larva and separated from notogaster by a suture. Lateral carina moderately developed. Three pairs of prodorsal setae as in the larva. Seta *ro* short and curved externally, measuring 19. Seta *le* longer, being 52 in length. Barbs appear stronger at distal end. Seta *in* minute. Sensillus better developed with a longer stalk. One or two striations seen along posterolateral margins of the aspis. Prodorsal integument faintly punctated.

Notogaster (Plate-52, Fig.2)

Notogaster arched dorsally and with a round posterior end. Number of notogastral setae increased to 12 pairs (Table 12) with the appearance of setae c_2, c_3, c_p, d_2, e_2, h_1 and h_2. Existing setae longer than in the larva and show variation in length ranging from 32-48. All setae smooth. Integument of notogaster with less number of wrinkles than in the larva and with scattered punctations.

Ventral Region (Plate-52, Fig. 2)

Rutellum and chelicera more sclerotized. Infracapitulum with three pairs of setae as in larva. Pedipalp three segmented. Epimeral boundaries more pronounced. Epimeral setal formula 1-0-1-1. Seta of epimere I longer. All setae smooth. Genital area faintly marked with a single pair of sucker and three pairs of small, smooth setae (Table 13). Anoadanal plates rectangular. Each plate with five pairs of setae (Table 14) with the addition of the third pair of anal setae. The three pairs of anal setae inserted close together towards the inner margin, while

adanal setae located away from the margin. Integument of ventral region with less number of wrinkles.

Legs:

Four pairs. All monodactylous.

Deutonymph (Plate-52, Fig. 3)

Measurements (Table 11): Length: 471 (Range 462-486)
Width : 229 (Range 224-238)

Deutonymph could be distinguished by its moderate increase in body size and creamy white colour. It fed actively on the root, boring tunnels deeper into the root.

Prodorsum (Plate-52, Fig. 3)

Prodorsum better developed than that of the protonymph. Prodorsal setae increased to four pairs with the appearance of exobothridial seta *ex*. Seta *ro* measured 24. Seta *le* long, stout and measured 74. Seta *in* the shortest of all prodorsal setae, measured 10. The newly appeared seta *ex*, thin and 14 long. All prodorsal setae with pronounced insertional points. Bothridium and *ss* as in the previous stage. Lateral border of prodorsum with scattered foveolae. Punctations of integument more pronounced.

Notogaster (Plate-52, Fig. 3)

Notogaster convex with a round posterior border. 13 pairs of smooth notogastral setae (Table 12). Seta ps_2 appeared in this stage. Setae show variation in length ranging from 46-64. Integument of notogaster without wrinkles, but with punctations.

Ventral Region (Plate-52, Fig. 3)

Rutellum thick and broad with three notches. Chelicerae stout. Pedipalp three segmented. Epimeral setal formula 1-0-1-1. Seta of epimere 1 longer, barbed and tapering while others smooth. Genital plates rectangular, carrying five pairs of smooth setae (Table 13) and two pairs of genital suckers. Anoadanal plates also rectangular. Each plate bears three pairs of smooth, short setae at its inner margin. Two pairs of adanal setae present(Table 14). Seta ad_1 long and smooth inserted at a level between an_2 and an_3, ad_2 located at a far anterior position. Integument of ventral region without wrinkles.

Legs

Four pairs. All legs monodactylous

Tritonymph (Plate-52, Fig.4)

Measurements(Table 11): Length: 605 (Range 595-618)
Width : 292 (Range 286-302)

Tritonymph could be distinguished by its large body and wheat brown colour. It fed voraciously. One or two food boli could be always detected inside the gut.

Prodorsum (Plate-52, Fig. 4)

Prodorsum elongated. Seta *ro* short and blunt, measures 30 and inserted far below the anterior margin of the rostrum. Seta *le* long, barbed towards its tip and measures 92. Seta *in* small, measuring 10, inserted below the level of *le*. Seta *ex* thin and measures 20. Bothridium with lateral opening. *ss* with long stalk and club shaped head. Lateral

border of prodorsum with scattered foveolae. Integument of prodorsum exhibits punctations.

Notogaster (Plate-52, Fig. 4)

Notogaster convex with rounded posterior border. Fifteen pairs of setae (Table 12) with barbs towards tip. Setal insertions deep. Setae show variation in length ranging from 52-85. Integument of notogaster provided with round foveoles which become more distinct on the side. In between the foveoles micropunctations present. Integument with moderate sclerotisation.

Ventral Region (Plate-52, Fig. 4)

Rutellum thick and stout with three notches. Cheliceral digits with blunt teeth. Infracapitulum with three pairs of setae. Pedipalp with a chaetotaxy of 0-2-3-5. Epimeral boundaries distinct. Epimeral setal formula 1-0-1-1. Setal disposition as in the previous stage. Genital plates elongated with six pairs of smooth setae (Table 13) and three pairs of suckers. Anoadanal plates rectangular with five pairs of setae (Table 14), three pairs of anal and two pairs of adanal setae. Anal setae arranged close to each other along the inner margin while adanal setae located away from margin. ad_1 long and smooth, inserted at a level between an_2 and an_3 while ad_2 inserted far anteriorly. Integument of ventral region foveolated.

Legs

Four pairs. All legs monodactylous.

Adult:

Refer page 80.

Diagnostic features of life stages (Table 15)

Larva can be easily distinguished by its small size, fragile nature, creamy white colour, and transparent body. Indistinct aspis, five pairs of notogastral setae, absence of genital setae and genital sucker and hexapod condition characterise the larva. Twelve pairs of notogastral setae, three pairs of genital setae and a single pair of genital suckers help to distinguish protonymph from the larva. Deutonymph possesses integument without wrinkles, 13 pairs of smooth, notogastral setae, five pairs of genital setae and two pairs of genital suckers. Tritonymph characterised by moderately sclerotised integument, six pairs of smooth genital setae and three pairs of genital suckers.

Table 10 - Duration of Development in Various Life Stages of *A. (H.) chaliensis* sp. nov.

Sl. No.	Egg	Larva	IQ	Protonymph	II Q	Deutonymph	III Q	Tritonymph	IV Q	Total Days
1	4	11	3	14	3	17	5	19	6	82
2	4	12	4	15	4	18	5	20	6	88
3	5	12	4	15	4	18	5	20	6	89
4	4	11	3	14	3	17	4	19	6	81
5	4	11	3	14	3	17	4	19	6	81
6	5	12	4	15	3	18	5	20	7	89
7	4	11	3	14	3	17	4	19	6	81
8	4	11	3	14	3	17	4	19	6	81
9	4	11	3	14	3	17	4	19	6	81
10	4	11	3	14	3	17	4	19	6	81
Range	4-5	11-12	3-4	14-15	3-4	17-18	4-5	19-20	6-7	81-89

Table 11 - Measurements (in μm) of the Various Life Stages of *A. (H.) chaliensis* sp. nov.

Stage	L/W	1	2	3	4	5	6	7	8	9	10	Average	Range
Egg	L	180	175	183	177	181	180	175	178	184	177	179	175-184
	W	162	157	165	159	162	163	158	160	165	159	161	157-165
Larva	L	315	310	318	312	315	316	310	314	318	312	314	310-318
	W	165	160	169	163	165	166	161	163	168	163	164.5	160-169
Protonymph	L	385	380	398	384	386	392	382	388	398	385	387.8	380-398
	W	200	195	205	197	200	204	196	203	206	198	200.4	195-206
Deutonymph	L	471	462	485	470	480	484	470	480	486	478	476.6	462-486
	W	229	224	238	227	235	236	229	235	238	232	232.3	224-238
Tritonymph	L	605	595	615	604	610	614	602	608	618	606	606.7	595-618
	W	292	286	300	290	295	298	294	298	302	292	294.7	286-302
Adult	L	617	617	675	654	668	678	632	680	693	654	657.9	617-693
	W	322	312	346	318	322	336	318	340	348	224	328.6	312-348

Table 12 - Appearance of Notogastral Setae in Various Life Stages of *A. (H.) chaliensis* sp. nov.

Stage	*c*	*d*	*e*	*f*	*h*	*ps*	Total No. of Setae	Setae Appeared Anew
Larva	c_1	d_1	e_1	f_1		ps_1	5	
Protonymph	c_1, c_2, c_3, *cp*	d_1, d_2	e_1, e_2	f_1	h_1, h_2	ps_1	12	c_2, c_3, *cp*, d_2, e_2, h_1 & h_2
Deutonymph	c_1, c_2, c_3, *cp*	d_1, d_2	e_1, e_2	f_1	h_1, h_2	ps_1, ps_2	13	ps_2
Tritonymph	c_1, c_2, c_3, *cp*	d_1, d_2	e_1, e_2	f_1	h_1, h_2,h_3	ps_1, ps_2, ps_3	15	h_3 and ps_3
Adult	c_1, c_2, c_3, *cp*	d_1, d_2	e_1, e_2	f_1	h_1, h_2,h_3	ps_1, ps_2, ps_3	15	

Table 13 - Appearance of Genital Setae in Various Life Stages of *A. (H.) chaliensis* sp. nov.

Life stage	Genital setae present	Setae Appeared Anew
Larva	0	0
Protonymph	3 pairs	g_1 - g_3
Deutonymph	5 pairs	g_4-g_5
Tritonymph	6 pairs	g_6
Adult	9 pairs	g_7 -g_9

Table 14 - Appearance of Adanal and Anal Setae in Various Life Stages of *A. (H.) chaliensis* sp. nov.

Stages	Adanal Segment	Anal Segment	Setae Appeared Anew
Larva	ad_1, ad_2	an_1, an_2	0
Protonymph	ad_1, ad_2	an_1, an_2, an_3	an_3
Deutonymph	ad_1, ad_2	an_1, an_2, an_3	0
Tritonymph	ad_1, ad_2	an_1, an_2, an_3	0
Adult	ad_1, ad_2	an_1, an_2, an_3	0

Table 15 - Diagnostic Features of Various Life Stages of *A. (H.) chaliensis* sp. nov.

Life stage	Range of measurement (in µm)	Prodorsal setae	Notogastral setae	Nature of Notogastral setae	Epimeral setal formula	Genital setae	Genital sucker	Anal setae	Adanal setae	Nature of integument
Larva	L : 310-318 W: 160-169	*ro, le, in*	5 pairs	Smooth	1-0-1-0	Absent	0	2 pairs	2 pairs	White coloured with wrinkles
Protonymph	L: 380-398 W: 195-206	*ro, le, in*	12 pairs	Smooth	1-0-1-1	3 pairs	1	3 pairs	2 pairs	Pale white coloured with lesser number of wrinkles
Deutonymph	L: 462-486 W: 224-238	*ro, le, in, ex*	13 pairs	Smooth	1-0-1-1	5 pairs	2	3 pairs	2 pairs	Creamy white in colour with punctations
Tritonymph	L: 595-618 W: 286-302	*ro, le, in, ex*	15 pairs	Barbed at the tip	1-0-1-1	6 pairs	3	3 pairs	2 pairs	Wheat brown in colour with punctations and foveolae
Adult	L: 617-693 W: 312-348	*ro, le, in. ex*	15 pairs	Barbed more than half of its length	1-0-1-1	9 pairs	3	3 pairs	2 pairs	Wheat brown in colour with punctations and foveolae

PLATE 52

Morphological Features of Life Stages of *Atropacarus (Hoplophorella) chaliensis* sp. nov.

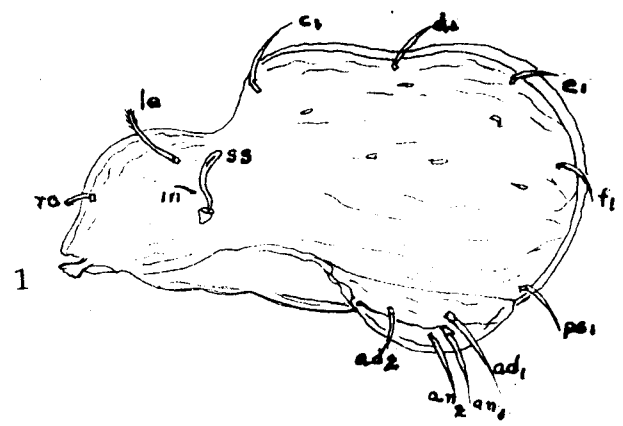
Fig. 1 Larva – L

Fig. 2 Protonymph –PN

Fig. 3 Deutonymph – DN

Fig. 4 Tritonymph – TN

PLATE 52



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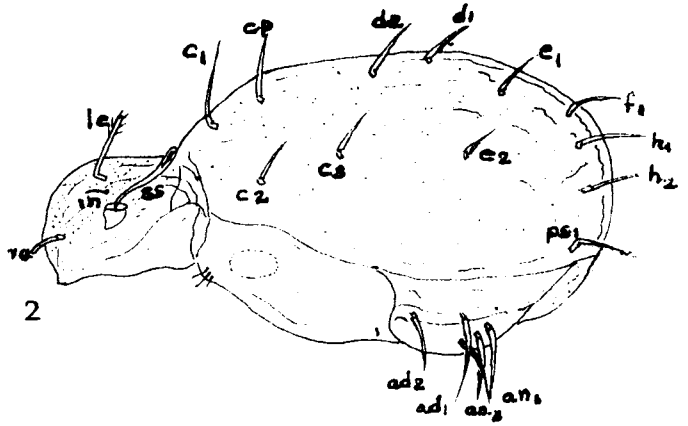

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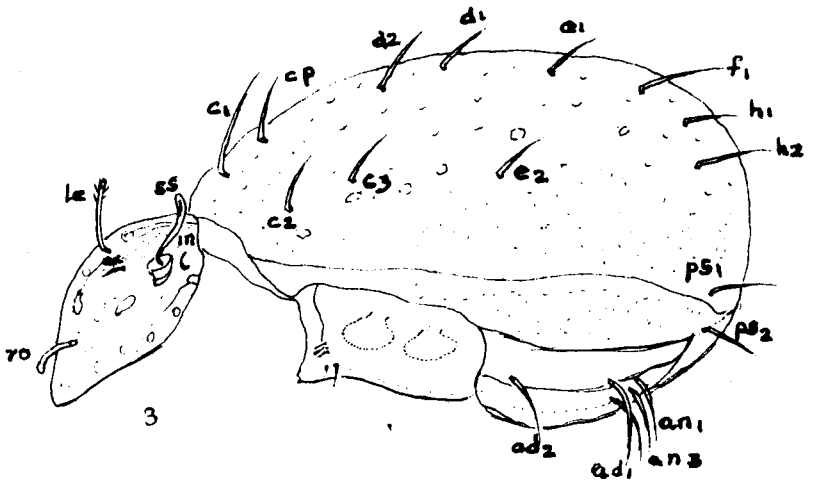

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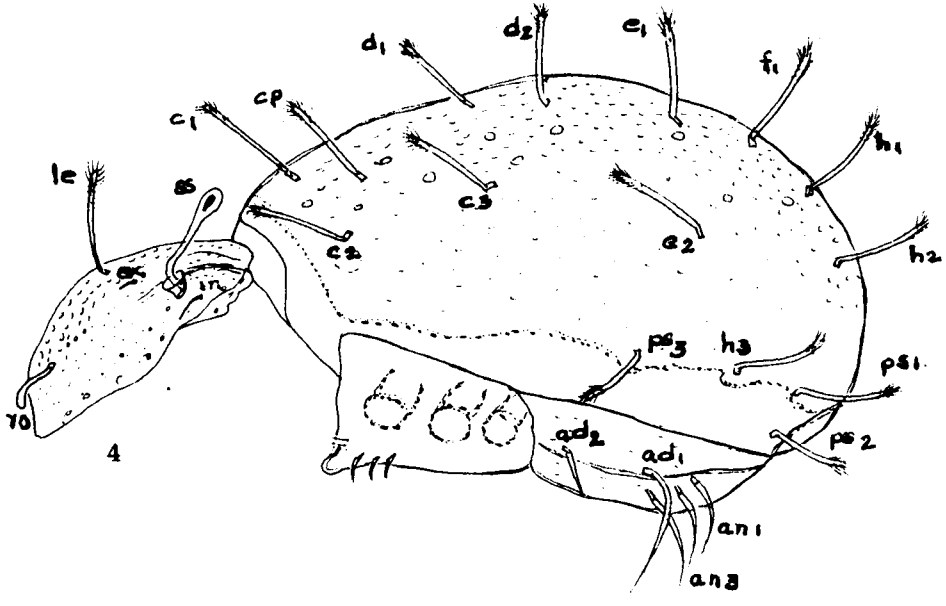

4

2. Postembryonic development of *Haplacarus davisi* sp. nov.

H. davisi was collected in large numbers from the decaying leaf litter of *X. zylocarpa* present in Kakkanchery site.

Oviposition

Gravid female deposited solitary eggs among the food materials provided. Body cavity of the female carried 2-3 eggs at a time. Usually a female deposited single egg a day but rarely two. The number of eggs laid by a female during her life time though not studied precisely, a female under laboratory condition laid eight eggs within a period of six days. Further observation helped to record the death of the same female within a few days.

Incubation and hatching

The egg during initial stage of development appeared swollen and milky white in appearance. After an incubation period of two weeks, it became creamy. Towards the time of hatching on the third week, the creamy white egg became light brown in colour. Before the emergence of the larva, at about 24-36 hours, a small slit appeared towards the anterior end along the longitudinal axis of the egg. This slit enlarged posteriorly and the hexapod larva emerged out by protruding its first pair of legs.

Duration of Life Stages (Table 16)

Larva (Plate-53, Fig. 6) after emergence remained inactive for about half an hour near the empty egg case. It became slowly active, stretched out its legs and started wandering about. When it recognised a preferred food,

feeding activity started which extended for a period of 15-16 days. Feeding became vigorous during the successive days. Quite often aggregates of larvae were found feeding on the leaf lamina. After the active period of feeding, the larva became quiescent for 8-9 days. During this period, the body appeared slightly swollen. Towards the end of the quiescent phase the body became transparent with the appearance of weakened areas along the postero-lateral region of the notogaster. Slits developed at the weakened areas got extended towards the anterior and posterior sides. The last pair of legs got extruded through the posterior slit. The pressure exerted by the moulting larva further extended the slit on both directions. The individual slowly emerged out by the gradual backward movements of the body. The process of moulting took 2-3 hours. The process of moulting was similar in all the subsequent nymphal stages. After the emergence, the nymphs remained motionless for about 10-15 minutes which represented a hardening period and then started moving and feeding. The protonymph (Plate-54, Fig. 1) emerged after the moulting led an active period of 18-21 days. Then it became quiescent for 8-9 days as in the first quiescent phase. Moulting released the deutonymph (Plate-54, Fig. 2). It entered the third quiescent phase after an active period of 21-23 days. The third quiescent phase appeared slightly longer than the second quiescent phase and it ranged from 9-12 days. The third moult produced the tritonymph. The tritonymph remained active for a period of 20-22 days. It entered the fourth quiescent phase which lasted for about 8-9 days after which moulting occurred, releasing the adult (Plate-54, Fig. 2). Thus *H. davisi* completed the development from egg to adult in 130-144 days.

Morphological description of life stages of *Haplacarus davisi sp. nov.*
(All measurements given in μm)

Egg:

Measurements (Table 17): Length: 230 (Range 230-240)
Width : 152 (Range 151-160)

Freshly laid eggs appeared white in colour, oval in shape and smooth in appearance. But microscopic scrutiny revealed fine reticulations over the egg. At the time of hatching, the colour of the egg gradually changed to light brown.

Larva (Plate-55, Figs. 1 & 2)

Measurements(Table 17): Length: 380 (Range 370-388)
Width : 228 (Range 222-232)

The newly emerged larva could be distinguished by its small wrinkled body and creamy white colour. Body soft and without any sclerotisation. Towards the end of the larval life, developed a pale brown colour. The larva possessed three pairs of legs.

Prodorsum (Plate-55, Fig. 1)

Anterior end of the prodorsum roughly triangular with broad base and conical apex. Lateral margin smooth but with a slight projection above the level of seta *exa*. Lamellae represented by weak ridge. All prodorsal setae smooth with pointed tip. Seta *ro* inserted below the rostral apex and measures 43. Seta *le* measures 37, inserted below the level of seta *ro*. Seta *in*, the smallest among all prodorsal setae, measures 17, inserted below the bothridium. Setae *exa* and *exp* arise from postero-lateral border of the prodorsum and measures 27 and 34 respectively. A band of closely set

punctations present below and between the level of *bo*, extending a little beyond the insertional points of seta *in* laterally. Sensillus (*ss*) well developed with eight branches. Bothridia (*bo*) directed laterally downwards.

Notogaster (Plate-55, Fig. 1)

Notogaster somewhat elongated in shape. Lateral and posterior margins wavy. Dorsosejugal region demarcated by a slightly convex line. Fourteen pairs of notogastral setae (Table 18) present. All setae smooth. Marginal setae longer. Integument of notogaster without any ornamentation but with wrinkles.

Ventral Region (Plate-55, Fig. 2)

Oral appendages visible from the ventral side. Pedipalp three segmented. Rutellum with three blunt teeth. Chelicera poorly developed. Infracapitulum with two pairs of simple, smooth setae, *a* and *h* (Table 19). Epimeral setal formula 3-1-3-0 (Table 20). Genital area not developed. Anoadanal plates fused with three pairs of setae (Table 22). All setae small and smooth.

Legs:

Three pairs. All legs monodactylous.

Protonymph: (Plate-55, Figs. 3 & 4)

Measurements(Table 17): Length: 457 (Range 450-465)
Width : 265 (Range 260-268)

Protonymph could be easily distinguished from the larva by its larger body size and four pairs of legs. Body light brown in colour and carried a few wrinkles. Integument ornamented with fine punctations.

Prodorsum (Plate-55, Fig. 3)

Prodorsum terminate anteriorly as a blunt, rounded rostrum and gradually becomes broader posteriorly. Lamellae more prominent than that of larva. All prodorsal setae well developed and exhibit increase in size than that of larva. All setae smooth. Seta *ro* 46 long, inserted far below the rostral apex. Seta *le* springs from the lateral border of prodorsum and measures 51. Setae *exa* and *exp* placed laterally measuring 60 and 45 respectively. Seta *in* inserted below the level of bothridial cup (*bo*) and measures 51. Bothridium with wide, laterally directed opening. *ss* with 10-12 branches. Prodorsum punctated.

Notogaster (Plate-55, Fig. 3)

Notogaster oval in shape with rounded posterior border. Sixteen pairs of notogastral setae (Table 18) present, ps_2 and ps_3 newly added. Setae exhibit moderate increase in length than in the larva. All setae smooth and simple. Eight notogastral bands seen, formed of chains of closely set area porosae, s_7 and s_8 incomplete medially. Lyrifissure *im* visible close to seta e_2 as a small slit. Integument of notogaster ornamented with fine scattered punctations.

Ventral Region (Plate-55, Fig. 4)

Gnathal appendages well developed. Pedipalp five segmented. Chelicera sclerotised. Rutellum fully developed with three blunt notches towards its tip. Infracapitulum well developed with three pairs of simple smooth setae (Table 19). Seta m_1 newly added. Epimeral region more pronounced than the larva. Epimeral setal formula 3-1-3-1 (Table 20). All

setae smooth. Genital plates wider than longer, carrying a pair of genital suckers and two pairs of smooth setae (Table 21). Preanal plate narrow. Anoadanal plates fused, longer, widest medially and carry three pairs of adanal and a single pair of anal setae (Table 22). Adanal setae ad_3 newly added. Lyrifissures *ia* and *ip* visible on ventral aspect. Area surrounding anoadanal and genital plates with punctations.

Legs

Four pairs. All legs monodactylous

Deutonymph (Plate-56, Figs. 1 & 2)

Measurements (Table 17): Length: 480 (Range 470-492)
Width : 267 (Range 260- 272)

Deutonymph could be distinguished by its slightly bigger size and pale brown colour. A few wrinkles present in the previous stage retained. Integument with fine punctations.

Prodorsum (Plate-56, Fig. 1)

Prodorsum flat and triangular, broader than longer. Rostral apex smooth and rounded. Lamellar ridge prominent. All prodorsal setae resemble those of the previous stage, but slightly longer. Seta *ro* measures 51. Seta *le* 74. Seta *in* longest measuring 81. Setae *exa* and *exp* almost of the same length, 62. All setae smooth with pointed tips. Bothridium and *ss* similar to that of protonymph. The prodorsum carries a transverse ridge between the points of insertion of *in* and formed of transverse striations.

Notogaster (Plate-56, Fig. 1)

Notgaster elongated, oval with round posterior end. Sixteen pairs of

notogastral setae (Table 18). Marginal setae ranging in size from 74-83 central setae measure 47-52. All setae smooth and simple. Eight notogastral bands present formed of chains of closely set oval or round area porosae. All bands complete, the last one slightly arched in the middle. Integument of notogster bears fine punctations as in the protonymph.

Ventral Region (Plate-56, Fig. 2)

Pedipalp well developed with five segments. Chelicera sclerotised. Rutellum with three blunt notches as in the protonymph. Infracapitulum with four pairs of smooth setae (Table 19). Seta m_2 newly added. Epimeral setal formula 3-1-3-3 (Table 20). Setae 4*b* and 4*c* newly added. All setae smooth in appearance. Genital plates with two pairs genital suckers and four pairs of smooth setae (Table 21). Three setae arranged along the outer border of the genital plate and the fourth pair along the inner border. Outer setae longer compared to the inner. A triangular aggenital plate present along the anterolateral border of genital plates. Preanal plate narrow. Anal and adnanal plates fused, three pairs of adanal and a single pair of anal seta present (Table 22). All setae smooth. Fissures *ia* and *ip* visible. Integument surrounding anoadanal and genital plates bears fine punctations.

Legs

Four pairs. All legs monodactylous.

Tritonymph (Plate-57, Figs. 1 & 2)

Measurements(Table 17): Length: 500 (Range 490-510)
Width : 293 (Range 280-300)

Tritonymph could be easily distinguished from other stages by its large body, brown colour and three pairs of genital suckers.

Prodorsum (Plate-57, Fig. 1)

Prodorsum broader than longer, flat, broad based with conical tip and a small lateral projection. Rostral apex smooth. Lamellae well demarcated. All prodorsal setae resemble those of the deutonymph but disposition vary considerably. Seta *ro* smallest, measures 54 inserted a little below the rostral apex. Seta *le* curves outwards measuring 78. Seta *in* inserted very close to *bo*, longest among all prodorsal setae, measuring 82. Setae *exa* and *exp* springs from the lateral margin of the prodorsum, measures 72 and 68 respectively. All setae smooth with pointed tips. *ss* with 12-14 branches. A transverse ridge formed of 6-8 crescentic elevations present between insertion points of seta *in*. Integument of prodorsum provided with rounded fovelolae which gradually change into crescentic elevations towards the rostral tip.

Notogaster (Plate-57, Fig. 1)

Shape of notogaster similar to that of deutonymph. Dorsosejugal line distinctly marked. Sixteen pairs (Table 18) of smooth notogastral setae. Marginal setae longer, range in size from 73-81 while central setae measure 54-64. Eight notogastral bands formed of closely arranged circular area porosae present. Notogastral bands s_3 and s_4 incomplete and become fused together towards the mid line. Integument of the notogaster bear rounded foveolae towards the posterior end.

Ventral region (Plate-57, Fig. 2)

Pedipalp, chelicera and rutellum as in the deutonymph. Infracapitulum with four pairs (Table 19) of smooth setae resembling those

of the previous stage. Epimeral setal formula 3-1-3-3 (Table 20) All setae smooth. Genital plates with three pairs of genital suckers and eight pairs (Table 21) of smooth setae. Four setae arranged along the outer border of the genital plate and four along the inner border, outer setae longer compared to the inner. Aggential plate triangular, situated along the anterolateral border of genital plate. Preanal plate narrow. Anal and adanal plates fused. Three pairs of adanal and a single pair of anal seta (Table 22) present. All setae smooth. Adanal setae decreasing in length from ad_1 to ad_3. Fissure *ia* visible outside the sejugal apodeme. Fissure *ip* located close to the postero-lateral margin of the body. Integument surrounding anoadanal and genital plates bears fine punctations.

Adult

Refer page 107.

Diagnostic Features of Life Stages (Table 23)

Larva minute and creamy white in colour. Body soft with fine wrinkles and integument without sclerotisation. Larva sluggish with three pairs of monodactylous legs. Sensillus well developed with eight branches. Notogaster bears 14 pairs of setae. Epimeral setal formula 3-1-3-0. Genital area not developed. Anoadanal plates fused with a single pair of anal and two pairs of adanal setae. All setae smooth. Protonymph developed the fourth pair of legs and eight notogastral bands, s_7 and s_8 incomplete medially. Sensillus with 10-12 branches. Epimeral setal formula 3-1-3-1. Genital plates developed with two pairs of setae and a single pair of genital suckers. The fused anoadanal plate with three pairs of adanal and a single

pair of anal setae. Deutonymph characterised by the presence of a prodorsal ridge formed of transverse striations between the points of insertion of setae *in*. Eight complete notogastral bands. Epimeral setal formula 3-1-3-3. Genital plates with four pairs of setae and two pairs of genital suckers. Aggenital plates triangular. Tritonymph largest of all nymphal stages and the body more sclerotised and brown in colour. Sensillus with 13-14 branches. Prodorsal ridge formed of 6-8 crescentic elevations stretched between insertional points of seta *in*. Notogastral bands s_3 and s_4 incomplete and fused together towards the midline. Genital plates with eight pairs of setae and three pairs of genital suckers. Integument with foveolae and punctations.

Table 16 - Duration of Development in Various Life Stages of *H. davisi* sp. nov.

Sl. No.	Egg	Larva	IQ	Proto nymph	II Q	Deuto nymph	III Q	Trito nymph	IV Q	Total Days
1	23	15	8	18	8	21	9	21	8	131
2	23	15	8	18	8	21	9	21	8	131
3	22	15	8	18	8	21	9	21	8	130
4	23	15	8	18	8	21	9	20	8	130
5	22	15	8	18	8	21	9	21	8	130
6	23	16	9	21	9	23	12	22	9	144
7	23	15	8	18	8	21	9	21	8	131
8	22	15	8	18	8	21	9	21	8	130
9	23	15	8	18	8	21	9	21	8	132
10	23	15	8	18	8	23	9	21	8	133
Range	22-23	15-16	8-9	18-21	8-9	21-23	9-12	20-22	8-9	130-144

Table 17 - Measurements (in μm) of Various Life Stages of *H. Davisi* sp. nov.

Life stage	Length /Width	1	2	3	4	5	6	7	8	9	10	Average	Range
Egg	L	230	236	232	230	234	236	238	232	230	240	234	230-240
	W	152	157	153	152	154	156	159	153	151	160	154.7	151-160
Larva	L	380	376	384	380	370	374	388	375	372	382	380.1	370-388
	W	228	226	230	228	222	224	232	226	224	221	226.9	222-232
Protonymph	L	457	450	465	462	457	460	464	454	462	460	459.3	450-465
	W	265	260	268	266	265	266	268	262	266	265	265.1	260-268
Deutonymph	L	480	488	490	470	475	480	492	486	478	484	482.3	470-492
	W	267	270	272	260	264	268	272	270	266	270	267.9	260-272
Tritonymph	L	500	506	495	493	510	506	505	490	492	508	500.5	490-510
	W	293	295	290	288	302	295	293	280	282	300	290.8	280-300
Adult	L	553	540	548	552	558	540	545	555	550	545	548.6	540-558
	W	320	310	316	320	322	310	314	320	318	314	316.4	310-322

Table 18 - Appearance of Notogastral Setae in Various Life Stages of *H. davisi* sp. nov.

Stage	*c*	*d*	*e*	*f*	*h*	*ps*	Total Number of Setae	Setae Appeared Anew
Larva	c_1, c_2, c_3	d_1, d_2, d_3	e_1, e_2	F_1, f_2	h_1, h_2, h_3	ps_1	14 pairs	0
Protonymph	c_1, c_2, c_3	d_1, d_2, d_3	e_1, e_2	F_1, f_2	h_1, h_2, h_3	ps_1, ps_2, ps_3	16 pairs	ps_2, ps_3
Deutonymph	C_1, c_2, c_3	d_1, d_2, d_3	e_1, e_2	F_1, f_2	h_1, h_2, h_3	ps_1, ps_2, ps_3	16 pairs	0
Tritonymph	c_1, c_2, c_3	d_1, d_2, d_3	e_1, e_2	F_1, f_2	h_1, h_2, h_3	ps_1, ps_2, ps_3	16 pairs	0
Adult	c_1, c_2, c_3	d_1, d_2, d_3	e_1, e_2	F_1, f_2	h_1, h_2, h_3	ps_1, ps_2, ps_3	16 pairs	0

Table 19 - Appearance of Infracapitular Setae in Various Life Stages of *H. davisi* sp. nov.

Stage	Setae Present	Total Number of Setae	Setae Appeared Anew
Larva	*a, h*	2 pairs	0
Protonymph	*a, h, m_1*	3 pairs	*m_1*
Deutonymph	*a, h, m_1, m_2*	4 pairs	*m_2*
Trytonymph	*a, h, m_1, m_2*	4 pairs	0
Adult	*a, h, m_1, m_2*	4 pairs	0

Table 20 - Appearance of Epimeral Setae in Various Life Stages of *H. davisi* sp. nov.

Stages	Epimere				Setae Appeared Anew	Epimeral setal formula
	1	2	3	4		
Larva	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	-	0	3-1-3-0
Protonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*	4*a*	3-1-3-1
Deutonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*	4*b*, 4*c*	3-1-3-3
Tritonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*	0	3-1-3-3
Adult	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*	0	3-1-3-3

Table 21 - Appearance of Genital Setae in Various Life Stages of *H. davisi* sp. nov.

Stage	Genital setae		Total number of setae	Setae Appeared Anew
	Inner Row	Outer row		
Larva	0	0	0	0
Protonymph	1	1	2 Pairs	2 Pairs
Deutonymph	1	3	4 Pairs	2 Pairs
Tritonymph	4	4	8 Pairs	4 Pairs
Adult	6	4	10 Pairs	2 Pairs

Table 22- Appearance of Adanal and Anal Setae in Various Life Stages of *H. davisi* sp. nov.

Stage	Adanal segment			Anal segment
	Seta	Total number	Seta appeared anew	No. of seta
Larva	ad_1 ad_2	2 Pairs	2 pairs	1 Pair
Protonymph	ad_1 ad_2 ad_3	3 Pairs	1 pair	1 Pair
Deutonymph	ad_1 ad_2 ad_3	3 Pairs	0	1 Pair
Tritonymph	ad_1 ad_2 ad_3	3 Pairs	0	1 Pair
Adult	ad_1 ad_2 ad_3 ad_4	4 Pairs	1 pair	1 Pair

Table 23 - Diagnostic Features of Various Life Stages of *H. davisi* sp. nov.

Nature of Sensillus	Larva	Protonymph	Deutonymph	Tritonymph	Adult
	Well developed with 8 branches	10-12 branches	10-12 branches	13-14 branches	13-14 branches
Prodorsal ridge	-	-	Between insertional points of setae *in* formed of transverse striations	Formed of 6-8 crescentic area porosae	Formed of 6-8 interrupted crescentic area porosae
Notogastral setae	14 pairs, smooth	16 pairs, smooth	16 pairs, smooth	16 pairs, smooth	16 pairs, smooth
Notogastral bands	not developed	8 bands, *s* 7 and *s* 8 incomplete medially	8, complete bands	8, *s* 3 and *s* 4 incomplete and fused together	as in tritonymph
Epimeral setal formula	3-1-3-0	3-1-3-1	3-1-3-3	3-1-3-3	3-1-3-3
Number of genital setae	0	2 pairs	4 pairs	8 pairs	10 pairs
Number of genital suckers	0	1 pair	2 pairs	3 pairs	3 Pairs
Aggenital plate	-	-	triangular	triangular	triangular
Number of adanal seta	2 pairs	3 pairs	3 pairs	3 pairs	4 pairs
Number of anal seta	1 pair	1 pair	1 pair	1 pair	1 pair
Legs	3 pairs, monodactylous	4 pairs, monodactylous	4 pairs, monodactylous	4 pairs, monodactylous	4 pairs, monodactylous
Length	380 (370-388)	457 (450-465)	480 (470-492)	500 (490-510)	549 (540-558)
Width	228 (222-232)	265 (260-268)	267 (260-272)	293 (280-300)	316 (310-322)

PLATE 53

life Stages of *Atropacarus (Hoplophorella) chaliensis* sp. nov. Fig.s. 1-5 and *Haplacarus davisi* sp. nov. Fig. 6

Fig. 1 Egg- showing longitudinal slit(LS)

Fig. 2 Life stages of *A (H.) chaliensis,* A- adult, E- egg

Fig. 3 Life stages of *A (H.) chaliensis,* L-larva, PN- protonymph

Fig. 4 Life stages of *A. (H.) chaliensis,* DN- deutonymph, TN- tritonymph

Fig. 5 Life stages of *A. (H.) chaliensis* showing tritonymph (TN) near moulting skin (MS) deutonymph (DN)

Fig. 6 Life stages of *H. davisi* showing larva (L) just emerged from egg leaving moulting skin (MS)

PLATE 54

Life Stages of *Haplacarus davisi* sp. nov. (Fig.s. 1&2) and *Heptacarus indicus* sp. nov. (Fig.s. 3-6)

Fig. 1 Actively feeding protonymph (PN) of *H. davisi*

Fig. 2 Actively feeding deutonymph (DN) and adult (A) of *H. davisi*

Fig. 3 Egg (E) of *Heptacarus indicus*

Fig. 4 Larva (L) and protonymph (PN) of *H. indicus*

Fig. 5 Larva (L) deutonymph (DN) and adult (A) of *H. indicus*

Fig. 6 Tritonymph (TN) and adult (A) of *H. indicus*

PLATE 55

Morphological Features of Life Stages of *Haplacarus davisi* sp. nov.

Fig. 1 Larva - dorsal view

Fig. 2 Larva -- ventral view

Fig.. 3 Protonymph - dorsal view

Fig.. 4 Protonymph - ventral view

PLATE 55

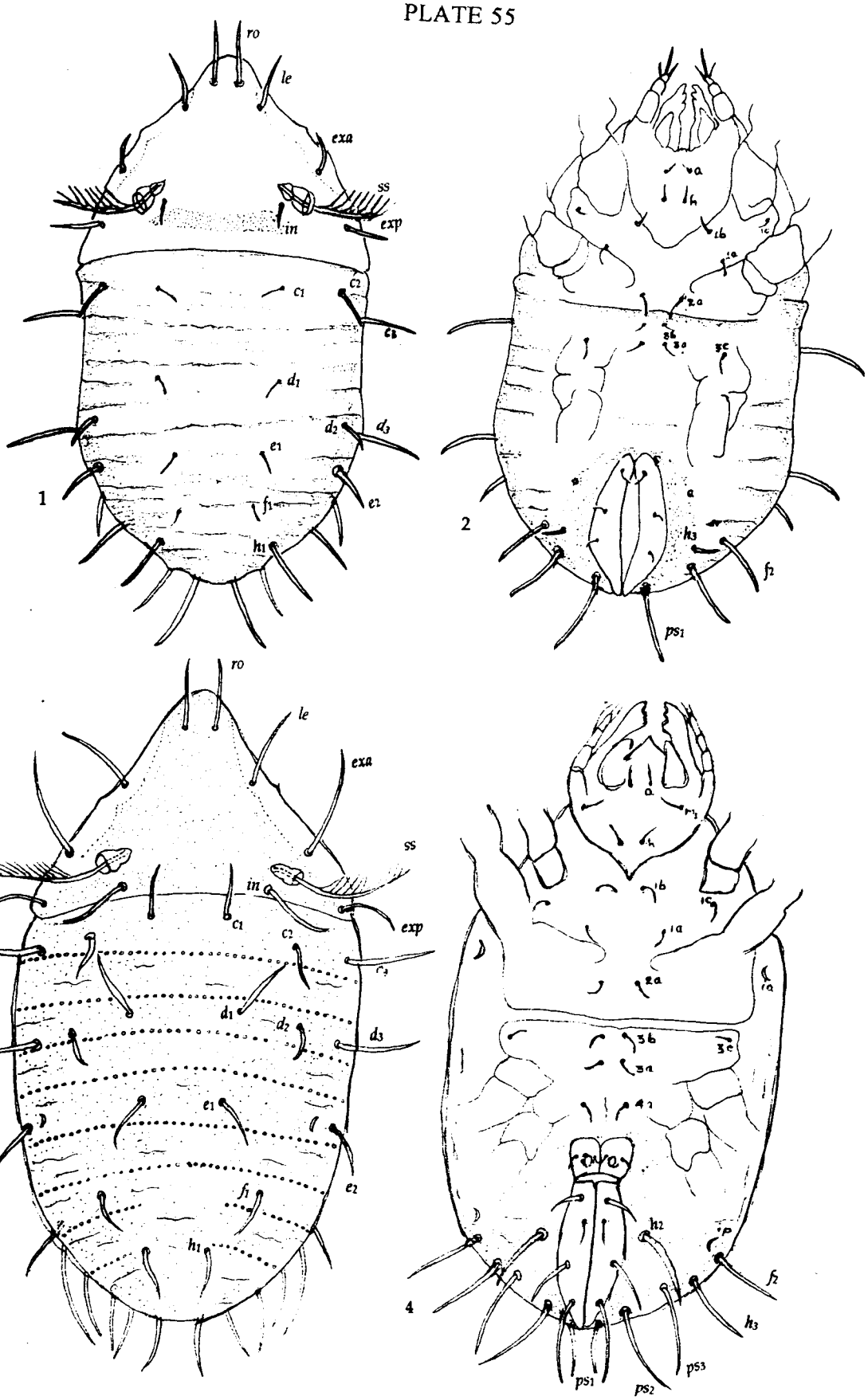

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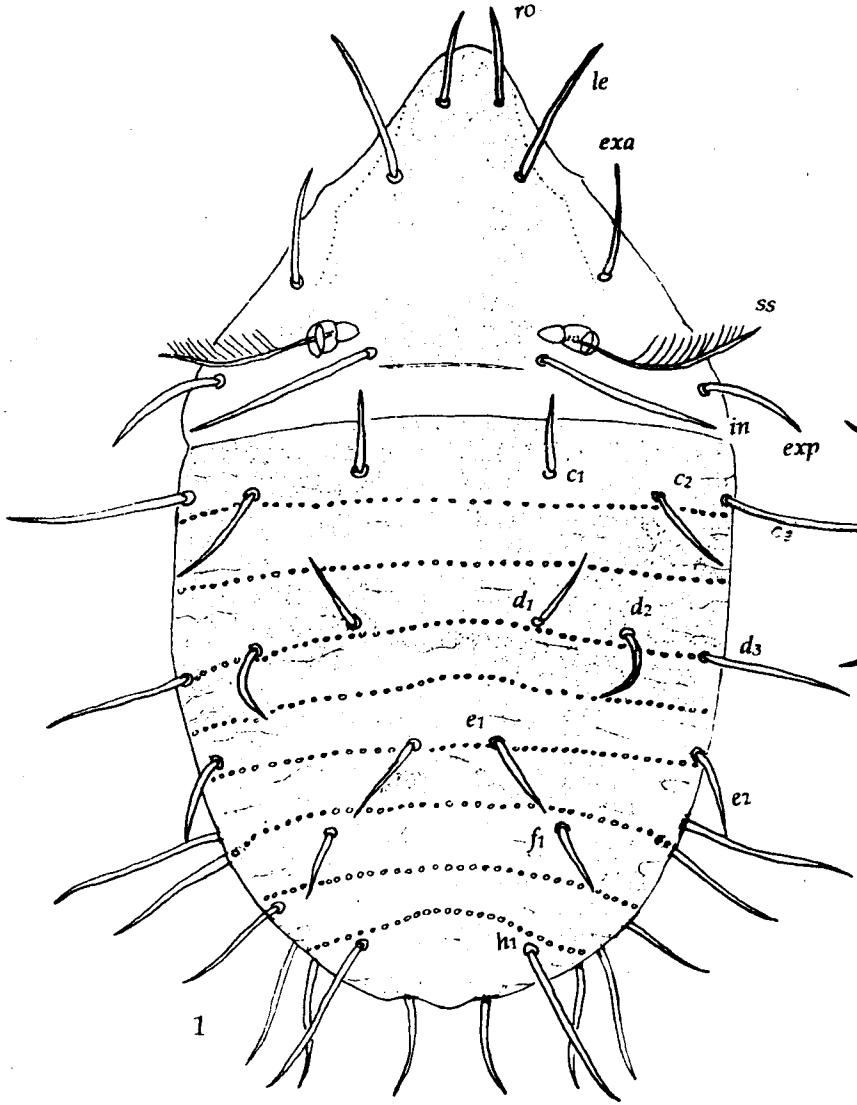
PLATE 56

Morphological Features of Life Stages of *Haplacarus davisi* sp. nov.

Fig. 1 Deutonymph- dorsal view

Fig. 2 Deutonymph- ventral view

PLATE 56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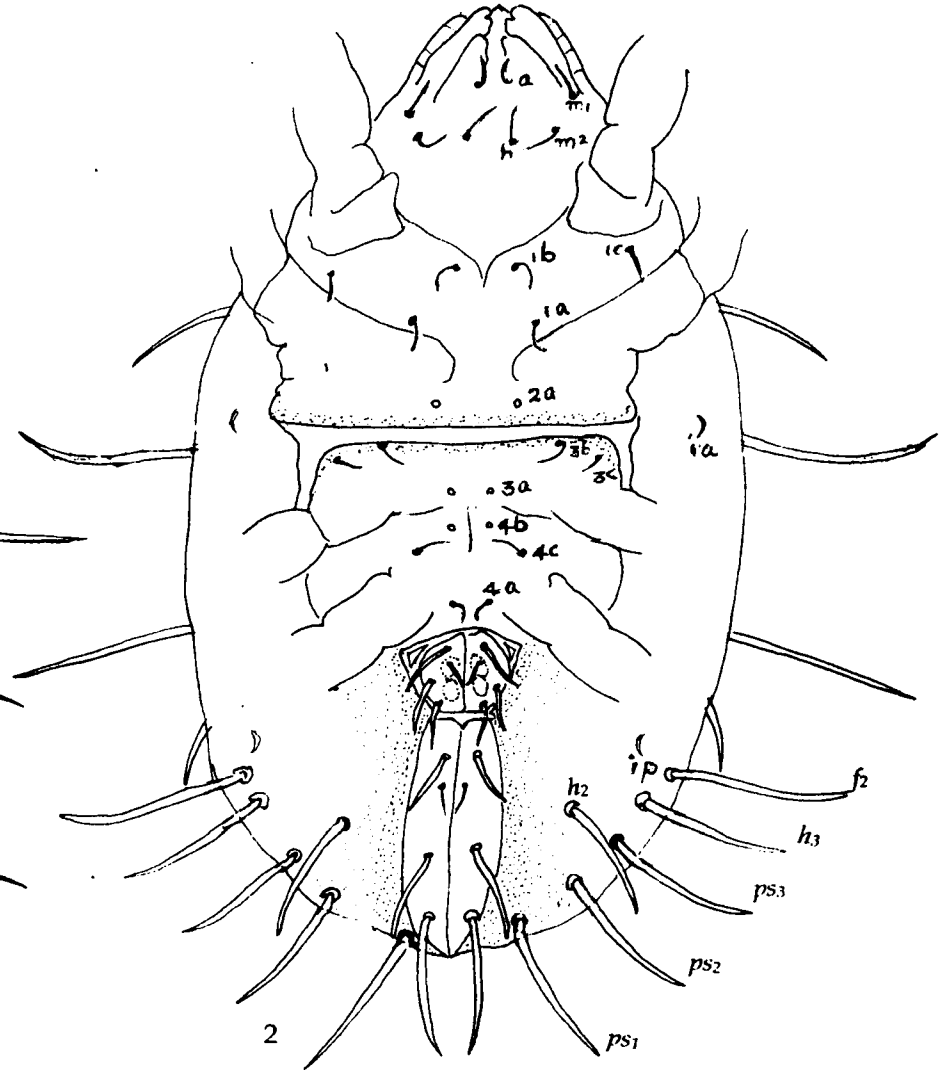
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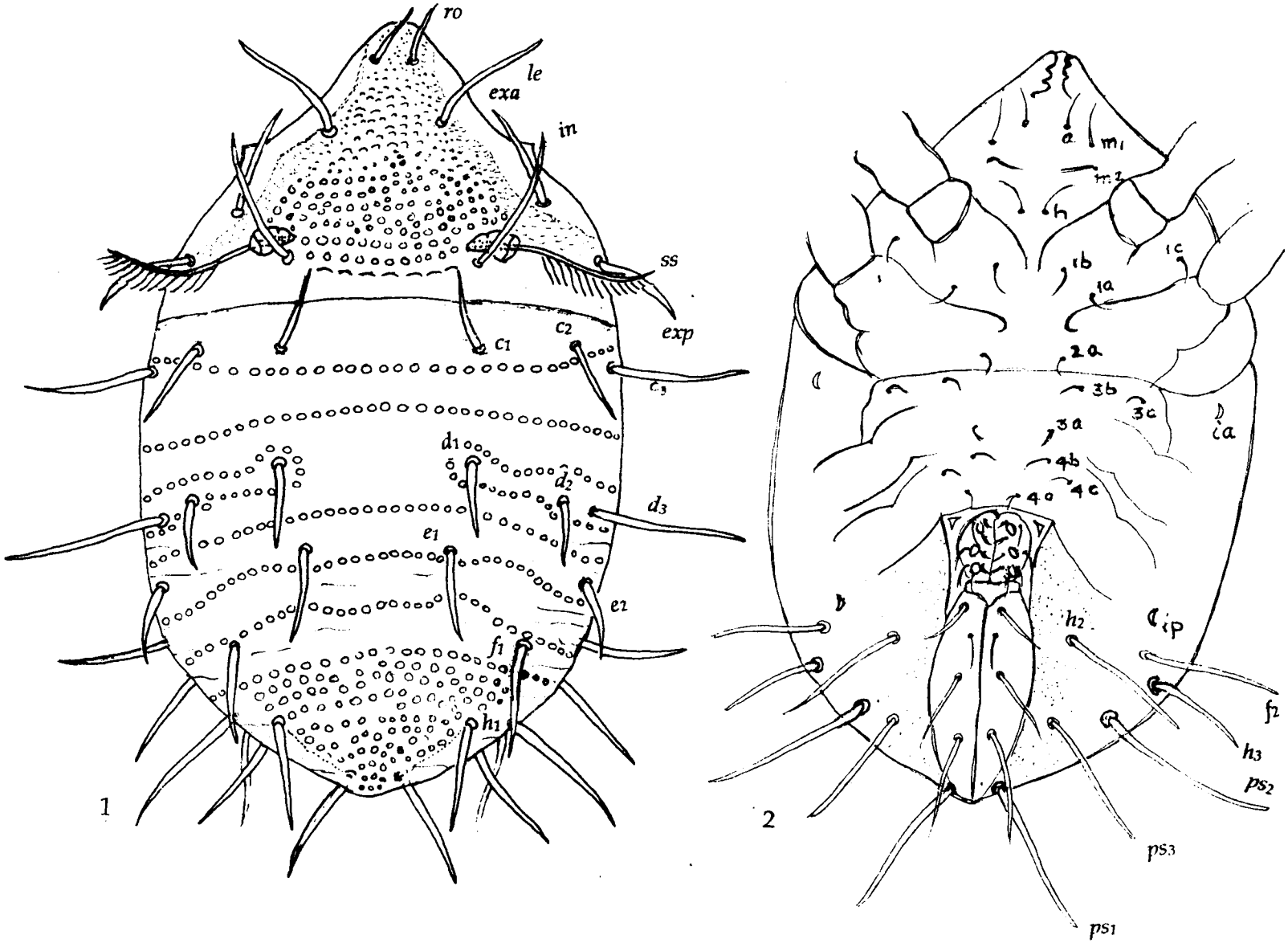
PLATE 57

Morphological Features of Life Stages of *Haplacarus davisi* sp. nov.

Fig. 1 Tritonymph- dorsal view

Fig. 2 Tritonymph-ventral view

PLATE 57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3. Postembryonic development of *Heptacarus indicus* sp. nov.

H. indicus was the only lohmanniid mite present in Chaliyam Beach which inhabited the decomposing drift wood.

Oviposition

Gravid females of *H. indicus* carried 1-2 eggs at a time. The female deposited solitary eggs on food material packed with faecal pellets (Plate- 54, Fig. 3)'. Quite often, eggs could be seen burried in tunnels bored into the wood. Because of this habit, a longitudinal section of the wood tissue revealed the presence of all the life stages, well protected inside the tunnels. The number of eggs laid by a female in the field could not be studied specifically due to the habit of ovipositing in tunnels. But under laboratory conditions a female laid upto 6-8 eggs. Continued observation helped to record the death of the female after about a week.

Incubcation and Hatching

Incubation period ranged from 22-26 days. After about 13 days of oviposition, a conical projection appeared towards the animal pole of the egg. Gradually the colour of the egg turned to light brown. Prior to hatching, a crescentic weak area developed along the antero-median portion of the egg. This area gradually got stretched out due to the pressure exerted by the developing larva inside. As a result, the weakened area ruptured a little ahead of the middle and the slit formed extended in both directions. The larva stretched out its legs and crawled out through the slit.

Duration of life stages (Table 24)

The larva (Plate-54, Figs. 4 & 5) which emerged out of the egg appeared very sluggish. It continued to remain in the tunnel bored into the wood. Immediately after emergence, larva remained motionless for about half an hour. This inactive period represented the hardening period. Then it gradually became active and started feeding on the woody tissue. Continued feeding by the larva led to the extension of the feeding tunnel. As feeding progressed, tunnel got packed with faecal pellets and the larva subsequently selected the adjacent region of the wood for further feeding. This active period of larval life continued for about 16-18 days. By this time, it increased in size and attained light brown colour. After the active period, it entered into the quiescent phase for 9-12 days. During this time, it suspended all life activities and remained motionless. Quiescent phase ended by moulting. The slow moulting process required 2-4 hours. The body during this phase became slightly swollen and translucent. The postero-lateral regions of the notogaster developed a few weakened areas on either side along which narrow slits appeared. Through these slits the last pair of legs extruded out. The slit became extended on both directions due to the pressure exerted by the emerging individual. The moulting individual gradually came out by a backward thrust of its body. The process of moulting remained more or less same in all the successive stages. Moulting of the first quiescent phase released the protonymph (Plate-54 Fig. 4). It fed actively on the woody tissue for about 19-22 days. Then it entered the second

quiescent phase which lasted for 9-11 days. Moulting of the second quiescent phase gave rise to the deutonymph (Plate-54, Fig. 5). The deutonymph continued to be active for 22-24 days, feeding voraciously on the wood after which it entered the third quiescent phase. The deutonymphal quiescence lasted for 10-12 days. It underwent moulting as in earlier phases releasing the tritonymph (Plate-54, Fig. 6). Tritonymph, the largest among all nymphal stages enjoyed an active life of 22-26 days. Active feeding by the tritonymph extended the tunnel further deeper into the wood. The fourth quiescent phase which followed extended for 10-12 days. The adult (Plate-54, Fig 6) emerged after the moulting of the fourth quiescent phase appeared brown in colour. Thus it took 141-154 days for *H. indicus* to complete its life cycle from egg to adult.

Morphological description of life stages of *H. indicus sp. nov.*

(All measurements given in μm)

Egg:

Measurements(Table 25): Length: 180 (Range 176-184)
Width : 130 (Range 126-132)

Freshly laid eggs appeared creamy white in colour and globular. As the incubation period advanced, the colour gradually changed to pale brown, which became deep brown just before hatching.

Larva (Plate-58, Figs. 1 & 2)

Measurements(Table 25) :Length: 290 (Range 278-298)
Width : 180 (Range 170-184)

The larva immediately after hatching appeared creamy white in colour, transparent, sluggish and characterised with several skin foldings. This stage could be identified by the weakly sclerotised creamy white coloured integument and three pairs of monodactylous legs.

Prodorsum (Plate-58, Fig. 1)

Prodorsum roughly triangular with a broad concave base. A transverse ridge extends the prodorsum a little below seta *ro*. Lamellae represented by weak ridge. Prodorsum bears the usual five pairs of setae viz., *ro, le, in, exa* and *exp* and the sensillus. All setae bear fine barbs on either side. Seta *ro* directed forwards, inserted at the base of the transverse ridge very close to the middle line and measures 40. Seta *le* inserted below the level of *ro,* but much laterally along the upper margin of lamellar ridge. These setae curve distally, measuring 33. Seta *in* inserted above the bothridial cup between the level of *ro* and *le,* but far behind. Setae *exa* and *exp* almost of the same size measuring 20. Bothridium small and cup-like. Sensillus fragile, pectinate with 6-7 branches. Dorsosejugal suture lighly convex in appearance. Prodorsum bears fine punctation except at the lamellar area.

Notogaster (Plate-58, Fig. 1)

Notogaster elongated in appearance with striking lateral skin foldings corresponding to segmentation. Width decreases towards posterior margin where it appears round. Fifteen pairs of notogastral

setae present (Table 26). Integument of notogaster exhibits fine punctations and several skin foldings.

Ventral Region (Plate-58, Fig. 2)

Rostral border ventrally covered by the pedipalp. Infracapitulum with wavy lateral margins and bears three pairs (Table 27) of setae viz., *a*, *h* and *m*. Rutellum intact with well developed notches. Chelicerae not visible. Pedipalp well developed with four segments. Epimeral area with definite boundaries. Epimere 4 not developed. Epimeral setal formula 3-1-2-0 (Table 28). All these setae small and simple, more or less of the same length. Genital area not developed. Anal and adanal segments fused. Two pairs of anal and four pairs adanal setae present (Table 30). The former ones smaller and smooth unlike the latter. Ventral plate with fine punctations and foldings at its postero-lateral regions.

Legs

Three pairs. All legs monodactylous

Protonymph (Plate-58 Figs 3 & 4)

Measurements: (Table 25) : Length 383 (Range 372-390)
Width 213 (Range 204-218)

This stage could be identified by four pairs of legs, bigger body size than the larva and better sclerotisation.

Prodorsum (Plate-58, Fig. 3)

Prodorsum conical in shape, ending in pointed rostrum anteriorly. Transverse ridge present behind seta *ro* more prominent.

Lamellar ridge more pronounced, reaching at the lateral boundary of prodorsal ridge. All prodorsal setae finely barbed. Seta *ro* inserted above the prodorsal ridge. Seta *in* sufficiently below and lateral to the level of *ro*, flexed downwards at its tip. Seta *in* straight springing above the level of bothridial cup. Setae *exa* and *exp* seen along the postero-lateral margin of lamella above and below the pseudostigmatic organ. Bothridium well developed. Sensillus with longer branches on anterior and shorter branches on posterior side. Dorsosejugal area below the suture marked by closely set transverse lines which give the skin a wrapped appearance in this area. Prodorsum with fine punctations.

Notogaster (Plate-58, Fig. 3)

Notogaster well developed with a few skin foldings and strongly differs from that of the larva in the number and arrangement of setae. Neotrichy well pronounced and hence setal nomenclature appears to be difficult. Twenty four pairs of notogastral setae present (Table 26). All setae possess fine barbs on one side and with a curved disposition. A few marginal setae longer than the central ones. Margin of notogaster bears four notches laterally. The entire surface of notogaster with fine punctations.

Ventral Region (Plate-58, Fig. 4)

Gnathosoma well broadened with characteristic contour. Infracapitulum well developed with same number of setae (Table 27); *a*, *h*, and *m* as in larva, but longer in size. Rutellum and chelicera found

closely set with one another. Rutellum with three prominent notches. Chelicerae with poorly defined teeth on movable and immovable digits. Pedipalp as in the larva. Epimeral setal formula 3-1-3-2 (Table 28). Setae *3c*, *4a* and *4b* newly added. All setae small and smooth. Genital area and plates developed each with a pair of barbed seta (Table 29) and a pair of genital sucker. Anterior end of anoadanal plate in contact with genital plate. Anoadanal plate fused. Five pairs of barbed adanal and two pairs of smooth anal setae present (Table 30). Fissure *ia* appears as a transverse slit outside the sejugal apodeme. Fissure *ip* occurs as a half moon shaped slit close to the anterior border of anoadanal plate. Pygidial neotrichy obvious. Integument outside the anoadanal area finely punctate.

Legs

Four pairs. All legs monodactylous.

Deutonymph (Plate-59, Figs. 1 & 2)

Measurements: (Table 25) Length 453 (Range 446-462)
Width 267 (Range 254-270)

This stage could be identified by the moderately sclerotised and light brown coloured skin. Median dorsal side slightly arched. Body carried one or two faecal pellets.

Prodorsum (Plate-59, Fig. 1)

Prodorsum broader than longer towards the basal region, much flatter than that of the protonymph. Lamellar ridge well pronounced and anteriorly reached the level of prodorsal ridge. Apex of rostrum

conical. Seta *ro* inserted above the level of the prodorsal ridge. Seta *le* lateral to and below the level of *ro*. Seta *in* much more longer than the other prodorsal setae and inserted above the level of bothridial cup (*bo*). Setae *exa* smaller than *exp*. Bothridium with lateral opening. Rachis of sensillus possess a bent a little after it emerges out of *bo*. Sensillus with about 15 branches anteriorly and a few spine-like branches posteriorly.

Notogaster (Plate-59, Fig. 1)

Notogaster oval in shape with rounded posterior end. Area below dorosejugal suture marked by closely set transverse bands.. Neotrichy more pronounced than in protonymph with 33 pairs of notogastral setae. All setae barbed on one side, slightly curved and without any schematic arrangement except a few setae along the margin. All setae appear to be of the same size and nature. Surface of notogaster heavily punctate and resembles that of protonymph.

Ventral Region (Plate-59, Fig. 2)

Infracapitulum well developed, somewhat oval in out line. Oral appendages well sclerotised and closely set that their identity less demarkated. Rutellum with three blunt notches. Chelicerae with well defined teeth on movable and immovable digits. Pedipalp well developed. Four pairs of setae on the infracapitulum (Table 27) *a, h,* m_1 and m_2, the last one appeared anew. All setae smooth and same in length. Epimeral setal formula 3-1-3-3 (Table 28). Seta 4*c* newly added. All setae smooth and simple. Genital plates much broader at

the anterior end. Each plate carries four pairs of barbed setae (Table 29) arranged in two rows of two pairs each. Inner setae smaller than the outer. Two pairs of genital suckers visible on the genital plate. A thin preanal plate unites the genital plate with anoadanal plates. Preanal plate with a posterior median projection. Anal and adanal plates fused. Five pairs of adanal and two pairs of anal setae present (Table 30). All the former setae barbed while latter smooth. Fissure *ia* visible outside the sejugal apodeme. The integument bears dense punctations along postero-lateral region of the ventral side.

Legs

Four pairs. All legs monodactylous.

Tritonymph (Plate-60, Figs. 1 & 2)

Measurements: (Table 25) Length 533 (Range 530-540)
Width 367 (Range 364-372)

This stage could be identified by the arched dorsal region. Integument more sclerotised and brown in colour. Due to profuse development of neotrichial setae, posterior one third of the body hairy in appearance.

Prodorsum (Plate-60, Fig. 1)

Prodorsum broad, flat and triangular. Lamellae well developed. Its anterior tip reaches upto the level of the transverse prodorsal band laterally. Rostrum curved downwards. Prodorsum broader than longer. Prodorsal setae resemble that of the deutonymph but with increase in size. Bothridium widely open laterally with long *ss*. Snsillus bears 17-18 long

branches on the anterior side and 6-8 small branches on the posterior side. The entire prodorsal surface bear dense punctations.

Notogaster (Plate-60, Fig. 1)

Notogaster elongated with rounded posterior end and slight conical projection antero-laterally. Dorsosejugal area very prominent. Notogastral neotrichy strong with 38 pairs of setae (Table 26). Neotrichial setae more towards the posterior one third of the notogaster. Setae do not exhibit any sequential arrangement. All setae curved towards the tip and barbed slightly on both sides. Integument of the notogaster with dense, fine punctation as in the previous stage.

Ventral Region (Plate-60, Fig. 2)

Infracapitulum fully developed with four pairs of setae (Table 27) as in the previous stage, *a, h,* m_1, and m_2. Setae simple.and smooth. Chelicerae and rutellum well sclerotised. Rutellum ends in three prominent knobs anteriorly. Pedipalp well developed with five segments. Epimerae with definite boundaries. Epimeral setal formula 3-1-3-4 (Table 28). Seta 4*d* newly added. All setae barbed. Anogenital area well developed. Genital plate divided by a transverse suture into anterior and posterior halves. Each genital plate carries seven pairs of barbed setae (Table 29), three in the inner row and four in the outer row, the former slightly smaller, than the latter. Three pairs of genital suckers present. Preanal plate narrow with a median downward projection posteriorly. Anal and adanal plates fused. Two pairs of anal and five pairs of adanal setae present (Table 30). Anal setae small and barbed. Adanal setae twice as long as anal setae.

Integument with dense punctations except in the anterior region as in the previous stage.

Legs

Four pairs. All legs monodactylous

Adult

Refer page 110.

Diagnostic features of life stages (Table 31)

Larva can be easily distinguished by its creamy white, transparent body, small size and hexapod condition. Notogaster bears only 15 pairs of setae. Epimeral setal formula 3-1-2-0. Genital plate and genital setae not developed. Larger body size, marked neotrichy, 24 pairs of notogastral setae, epimeral setal formula 3-1-3-2, single pair of genital sucker and single pair of genital setae help to distinguish protonymph from larva. Deutonymph possesses moderately sclerotised integument, brown colour, 33 pairs of notogastral setae, epimeral setal formula 3-1-3-3, two pairs of genital suckers and four pairs of genital setae. Thick and well sclerotised body, 38 pairs of notogastral setae, epimeral setal formula 3-1-3-4, genital plate with transverse suture, three pairs of genital sucker and seven pairs of genital setae characterise the tritonymph.

Table 24 - Duration of Development in Various Life Stages of *H. indicus* sp. nov.

Sl. No.	Egg	Larva	I Q	Protonymph	II Q	Deutonymph	III Q	Tritonymph	IV Q	Total Days
1	22	16	9	19	9	22	10	26	11	144
2	23	16	9	19	9	22	10	22	11	141
3	23	19	9	19	10	24	10	22	10	146
4	26	16	11	21	9	22	12	25	10	152
5	23	18	9	19	11	24	12	26	12	154
6	23	18	9	19	11	22	10	22	11	145
7	25	16	12	22	9	22	10	22	11	149
8	23	17	12	21	10	22	10	24	11	150
9	23	16	9	19	9	23	10	26	10	145
10	22	16	9	19	9	22	12	22	11	142
Range	22-26	16-18	9-12	19-22	9-11	22-24	10-12	22-26	10-12	141-154

Table 25 - Measurements (in μm) of the Various Life Stages of *H. indicus* sp. nov.

Sl. No.	Life Stage	L/w	1	2	3	4	5	6	7	8	9	10	Range	Average
1	Egg	L	180	176	180	182	178	184	180	176	182	180	176-184	179.8
		W	130	128	130	131	128	132	128	126	131	130	126-132	129.4
2	Larva	L	290	283	296	298	286	290	278	296	290	282	278-298	288.9
		W	180	174	183	184	178	181	170	184	180	174	170-184	178.8
3	Protonymph	L	383	372	390	382	388	378	374	383	388	380	372-390	381.8
		W	213	204	218	212	214	206	204	212	216	210	204-218	210.9
4	Deutonymph	L	453	460	448	454	458	446	453	462	452	460	446-462	454.6
		W	267	270	256	267	268	254	266	270	267	268	254-270	265.3
5	Tritonymph	L	533	530	538	530	540	532	542	540	530	540	530-540	535.5
		W	367	364	370	366	370	366	372	370	364	372	364-372	368.1
6	Adult	L	650	660	648	644	652	658	650	646	652	648	644-660	650.8
		W	382	388	380	372	382	386	380	378	382	378	372-388	380.8

Table 26- Appearance of Notogastral Setae in Various Life Stages of *H. indicus* sp. nov.

Stage	Total Number of Setae	Setae Appeared Anew
Larva	15 pairs	15 pairs
Protonymph	24 pairs	9 pairs
Deutonymph	33 pairs	9 pairs
Tritonymph	38 pairs	5 pairs
Adult	44 pairs	6 pairs

Table 27- Appearance of Infracapitular Setae in Various Life Stages of *H. indicus* sp. nov.

Stage	Setae present	Total Number of Setae	Setae Appeared Anew
Larva	*a, h, m*	3 pairs	0
Protonymph	*a, h, m*	3 pairs	0
Deutonymph	*a, h, m_1, m_2*	4 pairs	1 pair
Tritonymph	*a, h, m_1, m_2*	4 pairs	0
Adult	*a, h, m_1, m_2*	4 pairs	0

Table 28 - Appearance of Epimeral Setae in Various Life Stages of *H. indicus* sp. nov.

Stage	Epimere				Epimeral Setal Formula	Seta Appearing Anew
	1	2	3	4		
Larva	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*	0	3-1-2-0	0
Protonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*	3-1-3-2	3*c*, 4*a*, 4*b*
Deutonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*	3-1-3-3	4*c*
Tritonymph	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*, 4*d*	3-1-3-4	4*d*
Adult	1*a*, 1*b*, 1*c*	2*a*	3*a*, 3*b*, 3*c*	4*a*, 4*b*, 4*c*, 4*d*	3-1-3-4	0

Table 29 - Appearance of Genital Setae in Various Life Stages of *H. indicus* sp. nov.

Stage	Genital Setae in		Total No.	Setae Appearing Anew
	Inner row	Outer row		
Larva	0	0	0	0
Protonymph	0	1 pair	1 pair	1 pairs
Deutonymph	2 pairs	2 pairs	4 pairs	3 pairs
Tritonymph	3 pairs	4 pairs	7 pairs	3 pairs
Adult	6 pairs	4 pairs	10 pairs	3 pairs

Table 30 - Appearance of Adanal and Anal Setae in Various Life stages of *H. indicus* sp. nov.

Stage	Adanal Segment			Anal Segment
	Seta	No	Seta appeared anew	Seta No.
Larva	ad_1, ad_2, ad_3, ad_4	4 pairs	0	2 pairs
Protonymph	ad_1, ad_2, ad_3, ad_4, ad_5	5 pairs	1 pair	2 pairs
Deutonymph	ad_1, ad_2, ad_3, ad_4, ad_5	5 pairs	0	2 pairs
Tritonymph	ad_1, ad_2, ad_3, ad_4, ad_5	5 pairs	0	2 pairs
Adult	ad_1, ad_2, ad_3, ad_4, ad_5	5 pairs	0	2 pairs

Table 31 - Diagnostic Features of Various Life Stages of *H. indicus* sp. nov.

Sl. No.	Life stages	Measurements	Notogastral Setae	Infracapitular Setae	Epimeral Setae	Genital plate and setae	Genital sucker	Pre-anal plate	Anal setae	Adanal setae
1	Larva	L 278-298 W 170-184	15 pairs	3 pairs	3-1-2-0	Not developed	Absent	Absent	2 pairs	4 pairs
2	Protonymph	L 372-390 W 204-218	24 pairs	3 pairs	3-1-3-2	Genital plate entire, seta 1 pair	1 pair	Absent	2 pairs	5 pairs
3	Deutonymph	L 446-462 W 254-270	33 pairs	4 pairs	3-1-3-3	Genital plate entire, setae 4 pairs	2 pairs	Present	2 pairs	5 pairs
4	Tritonymph	L 530-540 W 364-372	38 pairs	4 pairs	3-1-3-4	Genital plate with transverse suture, setae 7 pairs	3 pairs	Present	2 pairs	5 pairs
5	Adult	L 644-660 W 372-388	44 pairs	4 pairs	3-1-3-4	Genital plate with transverse suture, setae 10 pairs	3 pairs	Present	2 pairs	5 pairs

PLATE 58

Morphological Features of Life Stages of *Heptacarus indicus* sp. nov.

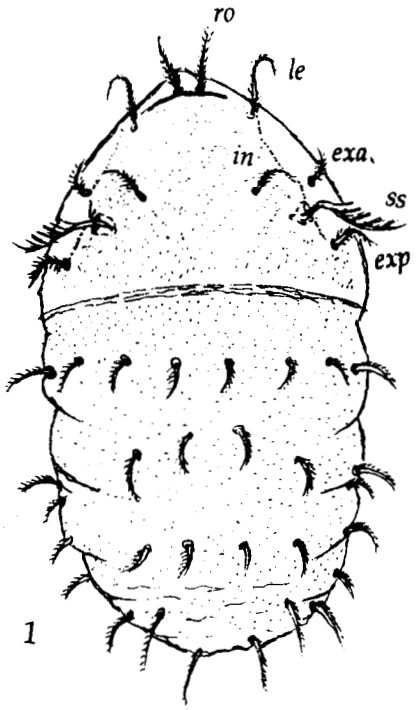
Fig. 1 Larva – dorsal view

Fig. 2 Larva – ventral view

Fig. 3 Protonymph – dorsal view

Fig. 4 Protonymph – ventral view

PLATE 58



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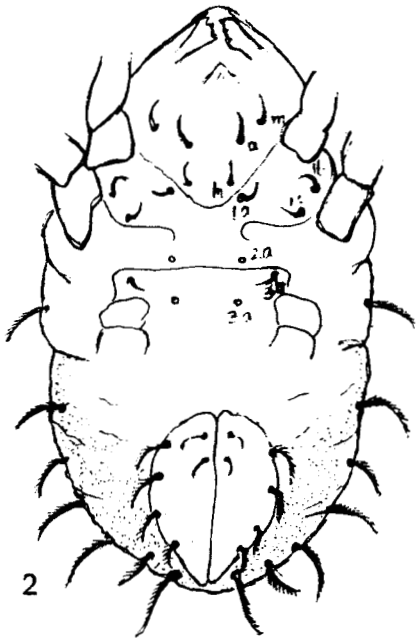

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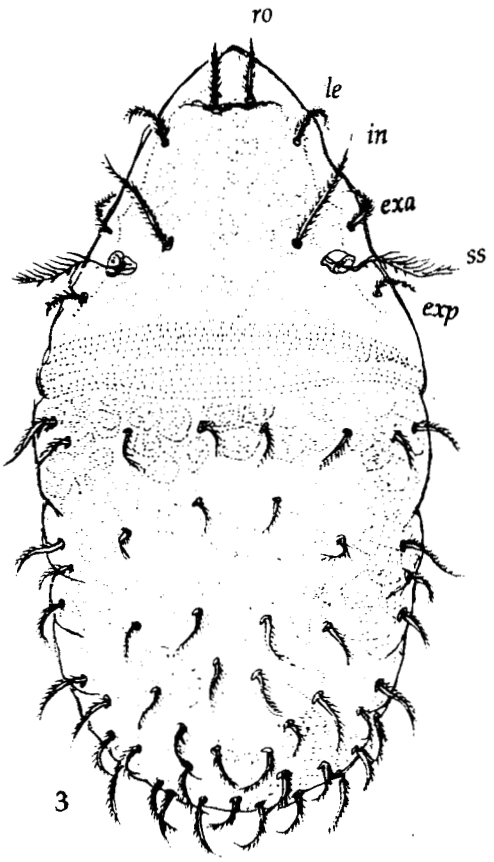

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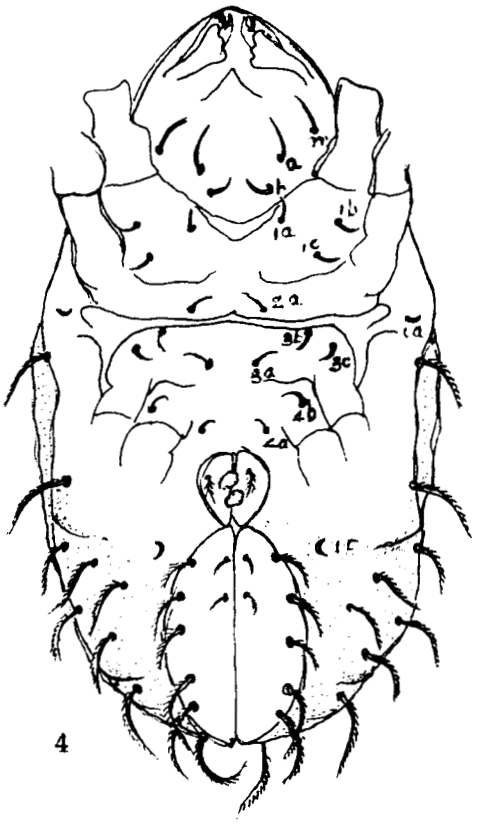


4

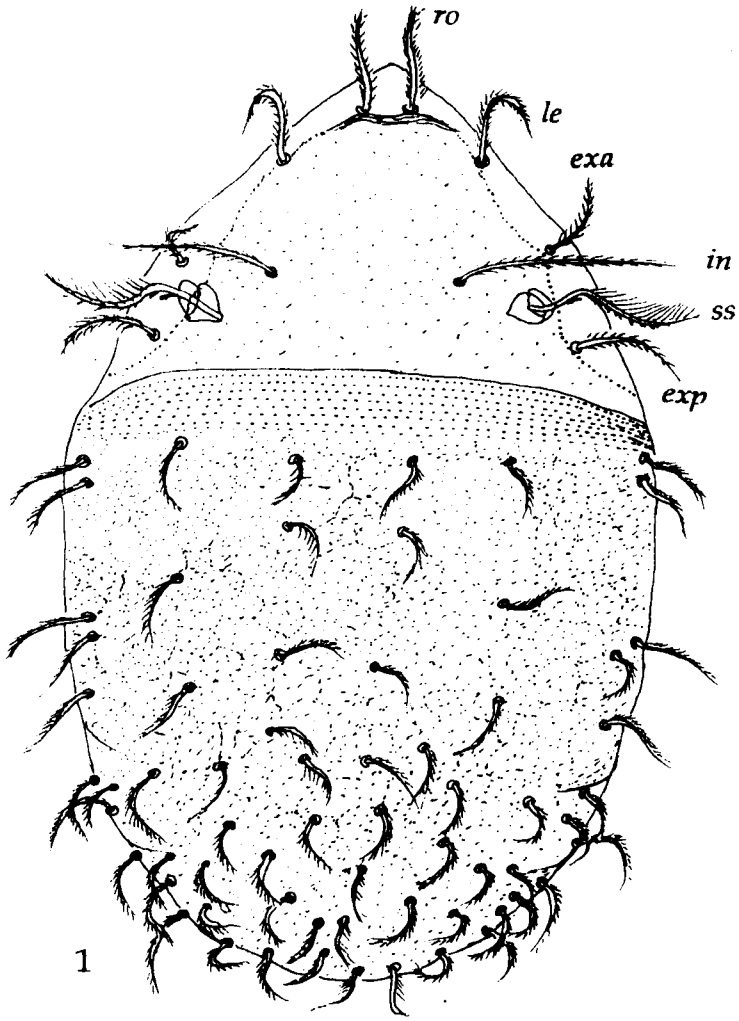
PLATE 59

Morphological Features of Life Stages of *Heptacarus indicus* sp. nov.

Fig. 1 Deutonymph - dorsal view

Fig. 2 Deutonymph - ventral view

PLATE 59



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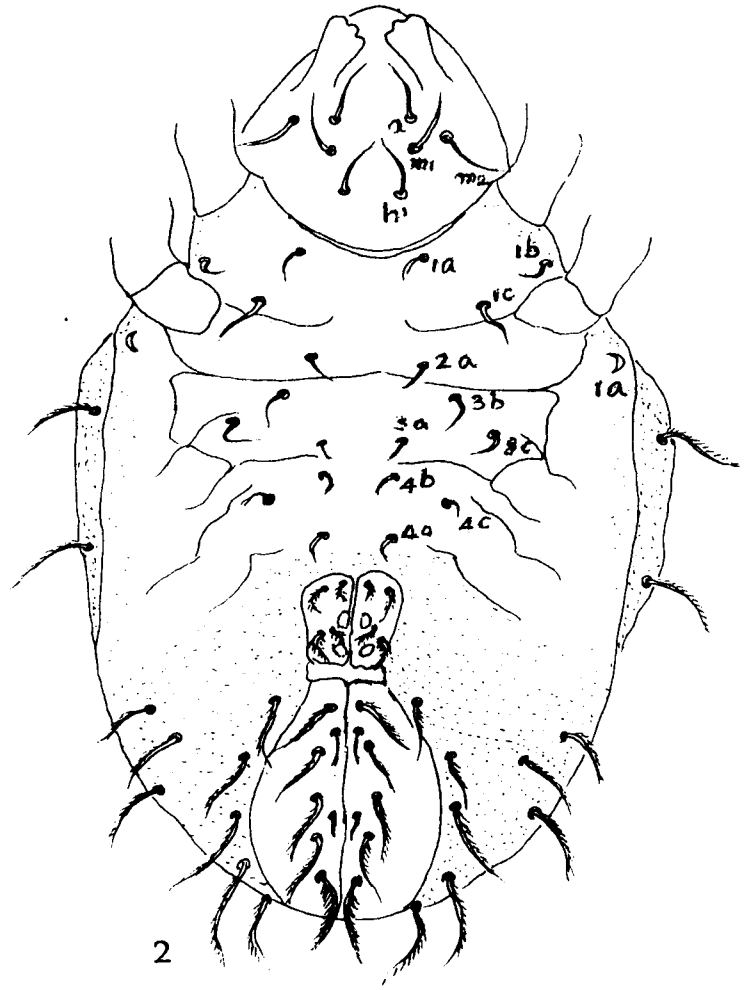


2

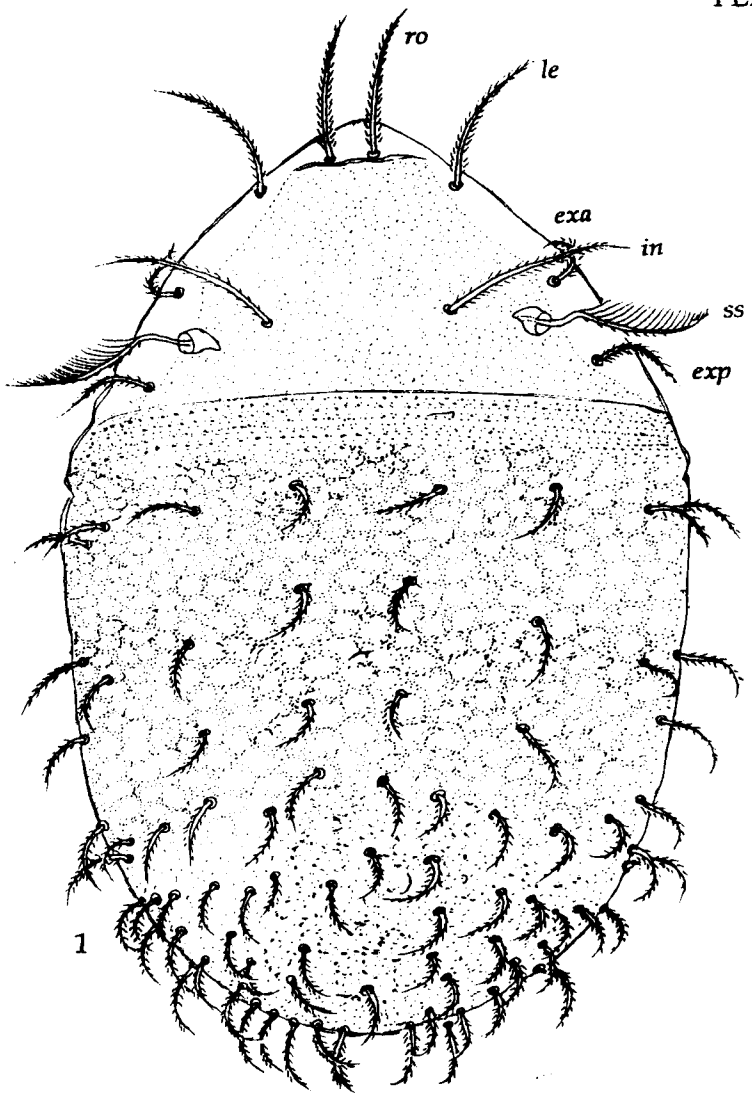
PLATE 60

Morphological Features of Life Stages of *Heptacarus indicus* sp. nov.

Fig. 1 Tritonymph – dorsal view

Fig. 2 Tritonymph – ventral view

PLATE 60



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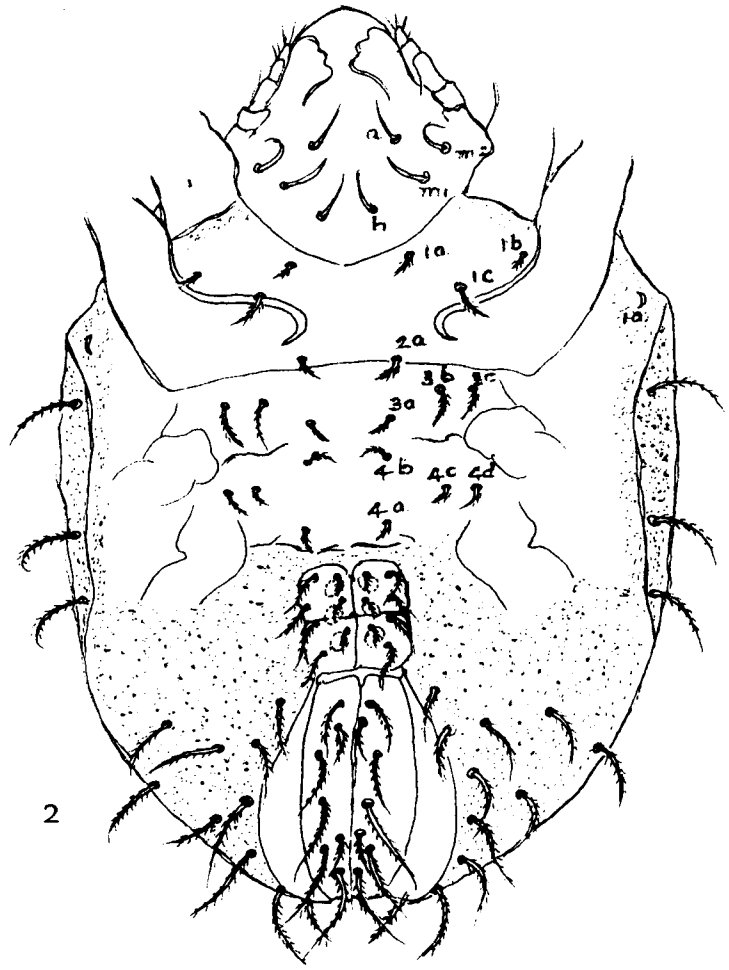


2

PART II
DISCUSSION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

DISCUSSION

The survey conducted in the first part of the present study brought to light the numerical abundance of oribatid mites in all the selected sites. This can be attributed to two main behavioural responses of these cryptic organisms. The extreme diversity of their nutritional behaviour allowed them to exploit most of the food substrates available in their natural habitat. The other aspect relates to their high fecundity and reproductive potency. Hence study on reproductive behaviour and life history stages of these mites assume special significance.

Reproductive behaviour in oribatid mites is initiated with the deposition of eggs by gravid female. Oribatid mites differ in their ovipositional bhaviour. In the present work, all the three species considered for study of postembryonic development viz., *A. (H.) chaliensis, H. davisi* and *H. indicus* were found to deposit solitary egg as was noted by earlier investigators like Cordo and De Loach (1976) in *O. terebrantis,* Haq and Ramani (1984) in *P. bengalensis,* Clement and Haq (1984) in *P. malabarica* and Sumungala and Haq (1995, 1995a) in *O. terebrantis.* It may be considered that all the three species studied preferred to deposit solitary egg, for minimising the chances of internal competition among the immature stages for food and shelter within their respective microhabitat. This is quite imperative when the highly lethargic and sluggish nature of the immature stages of these species is considered. The voracious feeding habit of the immatures may lead to fast depletion of the available food if all

the individuals are staying together. Possibly, laying solitary egg minimizes such causalities and enables maximum utilisation of the available resources.

In several instances, females were found searching for appropriate place to deposit the eggs. *A. (H.) chaliensis* bored into the root of *C. gigantea* producing tunnels and laid the egg. *H. indicus* also followed a similar pattern of oviposition within tunnels in the wood. *H. davisi* deposited the egg among the food materials, preferably under the leaf surface. This habit of ovipositing in selected places by gravid females had been reported by earlier workers. Arlian and Woolley (1970) found that females of *L. cidarus* deposited eggs either singly or in groups in a hole in the substratum or food material or hidden under debris, food or fungus. *P. bengalensis* was reported to lay single egg in the culture cells as well as on leaf fragments by Haq and Ramani (1984). Shereef and Haq (1992) found that females of *G. triquetra* inserted the ovipositor into the fungal cushion and deposited eggs in batches. Sumangla and Haq (1995) noticed the adults of *O. terebrantis* cutting holes into leaf and laying the eggs. It is clear from the above observations that oribatid mites have evolved mechanisms to safeguard their eggs and immatures. Eggs deposited within the tunnels in the wood as in the case of *A. (H.) chaliensis* and *H. indicus* or among the food and under leaf surface as in the case of *H. davisi* remain protected from desiccation and predation by other animals. Apart from this, egg deposition on or in or among the food materials provide ready access of foods to the emerging larva. This would be of great advantage to immatures, particularly to newly emerged, immobile and fragile larval

stages.

The study showed that the period of incubation ranged from 22-26 days in both the lohmanniid mites viz., *H. davisi* and *H. indicus* while the same was 4-5 days in the phthiracarid mite, *A. (H.) chaliensis*. Shereef (1976) reported that incubation period in *P. aciculatus* was 12 days and *L. egypticus* 18 days. Incubation period in *G. triquetra* was found to be 8-10 days by Shereef and Haq (1992). *O.terbrantis* was found to have a shorter incubation period of 5-6 days as reported by Sumangala and Haq (1995). Haq and Ramani (1984) reported that *P. bengalensis* had an average incubation period of 4.1 days. From the study, it is thus clear that incubation period for lohmanniid mites is much higher compared to other oribatid mites. Lohmanniid mites possessed larger body which necessitated much more metabolic activity during ontogenic development. This in turn may lead to a corresponding extension of the incubation period as was seen in the current study.

Observations made in the present study showed that in all the three cases, prior to hatching the colour of the egg became light brown. This may be due to the development of amber pigmentation. Sengbush (1954), Sengbusch and Sengbusch (1970), Arlian and Woolley (1970), and Sumangala and Haq (1995) reported the development of colour in the eggs of *G. elimatus, O.nitens, L. cidarus* and *O. terebrantis* respectively before hatching. The period of incubation is a time of intense metabolic activity where breakdown of the stored food material occurs followed by synthesis of new protoplasm. By-products of some of these metabolic reactions may get deposited on the egg envelope imparting it various hues. In addition,

the metabolic wastes of the developing individual may also be added to the egg envelope. This finally lead to the transformation of the original transparent egg envelope into a rather opaque and tainted membrane.

An analysis of the data on duration of individual instars and total duration of development showed that in lohmanniid species the total duration as well as individual duration of immature stages were remarkably greater than that of the phthiracarid species. This was well evidenced in the case of *A. (H.) chaliensis, H. indicus,* and *H.davisi* which took 81-89, 141-154 and 130-144 days respectively to complete development from egg to adult. The two lohmanniid mites studied completed their ontogenic development on an average of 147.5 and 132.2 days respectively by *H. indicus* and *H. davisi.* Shereef (1976a) traced the development of two lohmanniid mites viz., *P. aciculatus* and *L. egypticus* and reported that they also took longer duration of 71 and 101 days respectively to complete the life cycle. Haq (1978) found that *L. ornatissimus* completed the development from egg to adult in 178.4 days. All these may lead to think that members of a given oribatid family follow the same pattern of development with minor species specific variations.

The three macrophytophagous mites viz., *A. (H.) chaliensis, H. davisi* and *H. indicus* considered for developmental biology, took sufficiently long time to complete their life cycle. This prolonged developmental period in its turn, creates minimum number of annual generations in the field condition. On the contrary, microphytophagous and pnaphytophagous species were found to complete their development within a shorter duration. Shereef (1971) reported that *Granuloppia* sp., *B. meridionalis,*

E. geographica, S. subverticillipes and *P. kamenskii* completed their life cycle in 31, 46, 56, 62 and 91 days respectively. The total developmental periods in the cases of *A. longisetosus, G. flabellifera,* and *G. longipluma* were found to be 34.4, 24.4 and 24.8 days respectively (Haq and Clement, 1980). Sumangala and Haq (1995) reported that *O. terebrantis* took 21-23 days for completing development from egg to adult. The shorter developmental period thus helped the microphytophagous and panphytophagous species to have more number of annual generations and hence their population was found exceedingly high in the field as compared to macrophytophagous species studied here. Soil as a natural system, thereby helps to support the existence of a variety of oribatid population having diversity in form, structure, duration and function.

A detailed study on the morphology of the juvenile stages in all the three cases viz., *A. (H.) chaliensis, H. indicus* and *H. davisi* showed that the larva was always a hexapod without genital plates. Arlian and Woolley (1969) while describing the life stages of *L. cidarus* reported the hexapod nature and absence of genital plates as characteristic of the larval stage. These characters of larvae were also reported by Clement and Haq (1984) in *P. malabarica,* Ramani and Haq (1984a) in *P. bengalensis,* Haq and Shereef (1992) in *G. uniqua* and Sumangala and Haq (1995) in *O. terebrantis.* This similarity exhibited by larvae of different oribatid species reveals the fact that oribatid mites in general follow a fundamental pattern of development. This is indicative of phylogenetic relationships between groups as viewed earlier (Wallwork, 1963).

It was also noted in the present study that the larvae were simple, without any generic or species specific characters. These characters appeared gradually as development advanced. This shows that general characters of the group appear first and species specific characters appear only towards the end of ontogenic development. This would have been the principle laid to depend exclusively on the adult for species identity.

The study showed that in the larvae of *A. (H.) chaliensis, H. indicus* and *H. davisi,* the notogastral setae were arranged in definite transverse rows. Seniczak (1978,1980,1989) reported a similar pattern of arrangement of setae in the larvae of *A. nitens, A. coleoptrata, Trichoribates trimaculatus* and *Melanozetes mollicomus.* According to Grandjean (1933), this arrangement of setae in transverse rows implies segmentation. Based on this, it can be concluded that the larval notogaster in all the three species studied consisted of six segments viz., C, D, E, F, H and PS. This clearly depicts ancestry of this group to segmented arthropods.

In all the three species studied viz., *A. (H.) chaliensis, H. davisi* and *H. indicus,* the later stages of developmet like the deutonymph and tritonymph exhibited a very high rate of food intake compared to the adult stages. The tritonymph appeared to be the most efficient feeder and their alimentary tract was reported to contain more abundant microflora (Stefaniak and Seniczak, 1976; Haq, 1987, 1996). This helped them to devour large quantities of food. Probably this would have been a reasonable attribute to the efficient role played by them in the decomposition of organic matter when compared to the adult. (Berthet, 1964; Webb, 1970; Haq, 1987, 1996).

PART II
MATERIALS AND METHODS

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

C. BIOPROCESSING OF ORGANIC RESIDUES BY ORIBATID MITES AND ORICULTURE TECHNOLOGY

Chapter XV – Materials and Methods
Chapter XVI – Observation
Chapter XVU – Discussion

MATERIALS AND METHODS

1. Evaluation of Nutrient Composition of Litter.

The potential of oribatid mites in enriching soil fertility and productivity was analysed quantitatively by recording the changes in the levels of four important macronutrients viz., Carbon (C), Nitrogen (N), Phosphorus (P) and Potassium (K) of litter before and after feeding by these mites. Soil samples collected from two different sites viz., the Chaliyam Beach (CB) and Kakkanchery (KS), which were characterised by wood and root accumulations of *C. gigantea* and leaf litter of *X. zylocarpa* respectively were considered for the above study. The collected samples of soils from the above sites were thoroughly extracted for 72 hours in order to remove all faunal members and transferred to three sets of earthen flower pots, each consisting of 10 numbers separately. In Experiment Set No. I, (soil sample from CB), 150 live adults of *A.* (*H.*) *chaliensis* were introduced while in Experiment Set No. II, 150 live adults of *H. davisi* were introduced. In Experiment III equal number of control pots were also maintained, without introducing oribatid mites. Soil samples in both experimental and control samples were adequately watered frequently and kept undisturbed for a period of about 10 months. These pots were covered with fine cloth to prevent the invasion by other organisms. After a period of 10 months, the soil samples of both experimental set ups and respective controls were subjected to chemical analysis for determining the quantities of C, P, N and K. Chemical

analysis was carried out in the District Soil Testing Laboratory, Thikkoti, following Jackson (1967). For chemical analysis, two grams each of soil samples were considered from experimental pots I and II respectively and 10 such samples were taken from each set. Equal numbers of control samples were also subjected to chemical analysis following the same procedure.

The quantitative differences in the various elements present in the test and control samples were recorded and analysed statistically by applying 't' test for 9 df at 5% significance. The differences in the quantities of the various elements were taken as an index for the assessment of feeding potential of the above two oribatid species considered

't' value was calculated following Rao (1996) applying the formula

$$t = \frac{\bar{d} - 0}{\frac{\sigma E}{\sqrt{n}}} \qquad \text{where,}$$

$\bar{d}$ = the average of difference between the two variables

n = number

σ = Standard deviation

A value > 2.262 (standard value of 't' at 9df at 5% level of significance) was considered as significant.

2. Assessment of Feeding Impact of Oribatid Mites on Plant Growth

An assessment of feeding impact of oribatid mites in terms of plant growth and productivity through oriculture technique was made by performing regular observation on the plant growth of a common pulse crop, *Vigna unguiculata* (cow pea), belonging to the family *Fabaceae*. Seeds of the above crop were sown in all the experimental and control pots which were kept for 10 months period for making comparative assessment. These pots were then kept in an open place so as to receive adequate sunlight. Frequent watering was made and the pots were covered with fine cloth to prevent invasion by any pests. Regular observation was made on germination, sprouting, growth, flowering, pod formation and other patterns of growth such as height and biomass of the plant, flowering time and length of pod. Plant height was measured on every 10th day and continued for a period of 60 days.

Biomass was determined by calculating the dry weight of the plant which completed 60 days of growth. Time of appearance of flowers was also noticed. Pod length was measured on the 14th day. Data obtained on the above lines of study were recorded, and analysed statistically.

PART II
OBSERVATION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

OBSERVATION

1. Feeding Efficiency of Oribatid Mites and Enhancement of Soil Nutrients

Results of quantitative studies made on the changes in the concentration of C, N, P and K as a result of feeding by two species of oribatid mites viz., *A. (H.) chaliensis* and *H. davisi* are represented in tables 32 and 33 and plate 61. In all cases, a quantitative increase was observed, irrespective of the variations in the nutrients. The percentage composition of organic C, N, P and K present in the litter of *C. gigantea* showed an increase by 0.2, 0.23, 0.003 and 0.005 respectively as a result of feeding by *A. (H.) chaliensis*. Similarly, the percentage composition of the above elements increased by 0.21, 0.12, 0.005 and 0.003 respectively when the leaf litter of *X. zylocarpa* was consumed and transformed to faecal pellets by *H. davisi*.

Results of statistical analysis of the data obtained in chemical analysis of litter following 't' test appeared highly significant (Plate-62). A comparative analysis of the data obtained as a result of 't' test performed for nutrient release by *A. (H.) chaliensis* and *H. davisi* enabled to account maximum significance in the case of N, P and K as a result of feeding by *A. (H.) chaliensis*. *H. davisi*, on the other hand disclosed highly significant result for release of organic carbon

2. Impact of Oribatid Mites on Soil Productivity and Plant Growth

Observation on plant growth (Pl-63)based on Oriculture technology further helped to confirm the potential of oribatid mites in

the enhancement of agricultural productivity. As represented in table 35 and plate 64, the plants of *V. unguiculata* reached a height of 33-34 cm by the 10th day in both experimental and control plants. From the second week onwards, plants grown in Experiment II showed moderate increase in height, reaching an average of 62.6 cm by the 20th day, unlike those of Experiment I and controls I and II which reached up to a mean height of only 51 cm. The plants in Experiment I showed faster growth from this state onwards and attained a height of 87 cm on the 30th day. In Experiment II, the plants attained an average height of 96.8 cm at this period while the control plants could reach only 67.68 cm on an average. On the 60th day, plants in Experiments I and II, and controls I and II reached a height of 173.2 cm, 196.2 cm, 132.6 cm and 134 cm respectively.

Results obtained on biomass assessment are presented in Table 36 and plate 65. Biomass of the plants grown in Experiment I was 104.3 gm while that of its control was 78.8 gm. Similarly, the biomass of plants grown in Experiment II was 108.1 gm while that of its control was 80 gm. The above results when analysed statistically using t-test were found significant at 9 df and 5% significance.

Data obtained on the inititiation of flowering in plants grown in experimental and control plants are presented in Table 37. The average time taken by plants in Experiment I to produce flowers was found to be 80.6 days while their controls took 97.2 days. Flower production initiated with an average of 77.4 days in the case of plants in Experiment II while their control plants produced flowers in 94.7 days. Thus, early

flowering could be observed in both experimental plants. Plants in Experiment I produced flowers 16.6 days before their controls while plants in Experiment II flowered 17.3 days before their controls. Thus, the study showed that plants took lesser number of days for producing flowers when the 'Oriculture Technology' was adopted by introducing sufficient numbers of oribatid mites. The study also showed that plants in Experiment II produced flowers first followed by plants in Experiment. I; control II and control I. Thus, the time taken for the appearance of flowers increased in the order Experiment II < Experiment I < control II < control I.

In all the plants, tiny fruits developed on the third or fourth day after the flowers opened which grew into pods. Table 38 shows the average length of pods in Experiments I and II, controls I and II which were 23.4, 23.6, 21.9 and 21.6 cm respectively. The pods produced by plants grown in experimental plants were comparatively bigger than those of the control plants.

Table 32 - Quantitative changes in nutrients before and after consumption by *A. (H.) chaliensis* on woody tissue of *C. gigantea* in Experiment I

Sl No.	Organic carbon %			Nitrogen %			Phosphorus %			Potassium %		
	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference
1	0.96	1.15	0.19	0.86	1.08	0.22	0.051	0.054	0.003	0.021	0.026	0.005
2	0.99	1.18	0.19	0.91	1.16	0.25	0.052	0.054	0.002	0.021	0.026	0.005
3	0.90	1.12	0.22	0.82	1.04	0.22	0.050	0.054	0.004	0.022	0.026	0.004
4	0.98	1.16	0.18	0.84	1.08	0.24	0.051	0.054	0.003	0.020	0.023	0.003
5	0.96	1.15	0.19	0.89	1.10	0.21	0.049	0.052	0.003	0.023	0.026	0.003
6	0.92	1.14	0.22	0.82	1.03	0.21	0.052	0.054	0.002	0.022	0.027	0.005
7	0.95	1.15	0.20	0.83	1.05	0.22	0.051	0.054	0.003	0.023	0.027	0.004
8	1.00	1.19	0.19	0.87	1.08	0.21	0.053	0.056	0.003	0.022	0.026	0.004
9	0.93	1.14	0.21	0.89	1.12	0.23	0.052	0.054	0.002	0.022	0.027	0.005
10	0.92	1.12	0.20	0.84	1.06	0.24	0.051	0.054	0.003	0.023	0.026	0.003
Mean	**0.95**	**1.15**	**0.20**	**0.85**	**1.08**	**0.23**	**0.051**	**0.054**	**0.003**	**0.021**	**0.026**	**0.005**
SD	**0.04**			**0.01**			**0.0006**			**0.0008**		
t value	**14.18**			**5.4**			**14.74**			**16.19**		

Table 33 - Quantitative changes in nutrients before and after consumption by *H. davisi* sp. nov. on leaf litter of *X. zylocarpa* in Experiment II

Sl. No.	Organic carbon %			Nitrogen %			Phosphorus %			Potassium %		
	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference	Before consumption	After consumption	Difference
1	1.52	1.73	0.21	1.12	1.24	0.12	0.021	0.024	0.003	0.056	0.059	0.003
2	1.52	1.73	0.21	1.12	1.25	0.13	0.022	0.026	0.004	0.054	0.055	0.001
3	1.49	1.73	0.24	1.10	1.24	0.14	0.026	0.032	0.006	0.042	0.046	0.004
4	1.52	1.68	0.16	1.12	1.24	0.12	0.026	0.031	0.005	0.047	0.048	0.001
5	1.55	1.75	0.20	1.12	1.23	0.11	0.024	0.029	0.005	0.047	0.050	0.003
6	1.50	1.76	0.26	1.12	1.24	0.12	0.021	0.025	0.004	0.042	0.047	0.005
7	1.52	1.73	0.21	1.14	1.24	0.10	0.025	0.028	0.003	0.050	0.052	0.002
8	1.52	1.70	0.18	1.13	1.24	0.11	0.029	0.032	0.003	0.044	0.047	0.003
9	1.54	1.73	0.19	1.11	1.22	0.11	0.024	0.028	0.004	0.046	0.049	0.003
10	1.52	1.76	0.24	1.12	1.26	0.14	0.021	0.025	0.004	0.045	0.047	0.002
Mean	1.52	1.73	0.21	1.12	1.24	0.12	0.023	0.028	0.005	0.047	0.050	0.003
SD	0.03			0.013			0.001			0.0012		
t value	22.12			2.91			12.956			7.11		

Table 34 - Consolidated statement of quantitative changes of nutrients of *C. gigantea* and *X. zylocarpa* before and after consumption by *A. (H.) chaliensis* sp. nov. and *H. davisi* sp. nov. in experiments I & II

Nutrient	Experiment I *C. gigantea* by *A. (H.) chaliensis*				Experiment II *X. zylocarpa* by *H. davisi*			
	% before consumption	*% after consumption*	*% increase in nutrient content*	*t-value*	*% before consumption*	*% after consumption*	*% increase in nutrient content*	*t-value*
Organic carbon	0.95	1.15	0.20	14.18	1.52	1.73	0.21	22.12
Nitrogen	0.85	1.08	0.23	5.4	1.12	1.24	0.12	2.91
Phosphorus	0.051	0.054	0.003	14.74	0.023	0.028	0.005	12.95
Potassium	0.021	0.026	0.005	16.19	0.047	0.050	0.003	7.11

Table 35 - Approximate height (in cm) of *Vigna unguiculata* for the first 60 days in oriculture using *A. (H.) chaliensis* sp. nov. and *H. davisi* sp. nov.

Sl No	*C. giganticus* inoculated with *A. (H.) chaliensis*												*X. zylocarpa* inoculated with *H. davisi*											
	Experiment I (in days)						Control I (in days)						Experiment II (in days)						Control II (in days)					
	10	20	30	40	50	60	10	20	30	40	50	60	10	20	30	40	50	60	10	20	30	40	50	60
1	35	52	87	104	129	166	34	51	60	88	102	122	32	58	92	121	144	187	33	51	68	85	108	137
2	34	52	87	108	135	180	33	50	65	80	98	135	33	60	96	145	148	190	32	51	67	91	102	138
3	33	50	86	102	125	160	33	51	68	85	99	128	34	62	100	150	150	192	35	52	71	88	104	129
4	35	52	88	110	138	182	35	52	73	90	106	140	35	67	98	162	162	208	32	50	68	90	108	131
5	34	51	87	105	132	178	35	52	72	88	104	138	35	66	98	158	158	204	34	51	70	86	101	131
6	34	51	87	105	132	178	35	52	68	85	104	138	35	66	98	158	158	204	34	51	70	86	101	135
7	35	52	88	110	138	182	35	52	73	90	106	140	35	67	98	162	162	208	32	50	68	90	108	135
8	33	50	86	102	125	160	33	51	72	88	99	128	34	62	100	150	150	192	35	52	71	88	104	129
9	34	52	87	108	135	180	33	50	65	80	98	135	33	60	96	148	148	190	32	51	67	91	102	138
10	35	52	87	104	129	166	34	51	60	88	102	122	32	58	92	144	144	187	33	51	68	85	108	137
Avg	**34.2**	**51.4**	**87**	**105.8**	**131.8**	**173.2**	**34**	**51.2**	**67.7**	**86.2**	**101.8**	**132.6**	**33.8**	**62.6**	**96.8**	**152.4**	**152.4**	**196.2**	**33.2**	**51**	**68.8**	**88**	**104.6**	**134**

Avg - Average

Table 36 - Biomass (in gm) of *V. unguiculata* after 60 days of growth in oriculture using *A. (H.) chaliensis* sp. nov. and *H. davisi* sp. nov.

Sl. No.	*C. gigantea* consumed by *A. (H.) chaliensis*		*X. zylocarpa* consumed by *H. davisi*	
	Experiment I	Control I	Experiment II	Control II
1	102	85	120	87
2	98	80	110	78
3	110	90	115	82
4	120	75	108	75
5	95	70	95	72
6	105	72	105	70
7	115	80	112	95
8	96	75	98	76
9	90	86	116	80
10	112	75	102	85
Average	104.3	78.8	108.1	80
t value	3.19		3.14	

Table 37 - Appearance of flower in *V. unguiculata* in oriculture using *A. (H.) chaliensis* sp. nov. and *H. davisi* sp. nov.

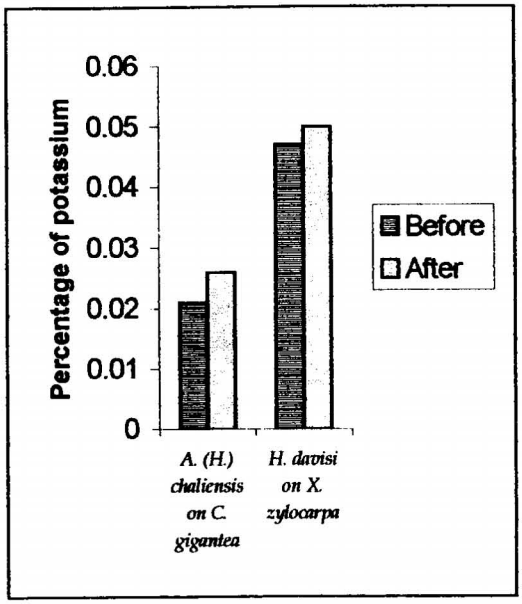
Sl. No.	Experiment I	Control I	Experiment II	Control II
1	82	96	78	92
2	82	92	80	96
3	80	98	72	93
4	79	100	77	98
5	81	94	81	91
6	80	105	76	96
7	82	98	78	98
8	81	102	80	94
9	80	91	74	90
10	79	96	78	99
Average	80.6	97.2	77.4	94.7

Table 38 - Length of pods (in cm) after 14 days of growth in *V. unguiculata* in oriculture using *A. (H.) chaliensis* sp. nov.and *H. davisi* sp. nov.

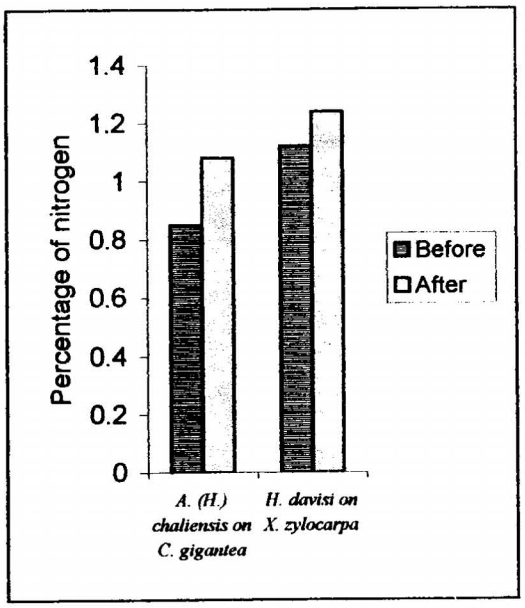
Sl. No.	Experiment I	Control I	Experiment II	Control II
1	24	22	23	22
2	25	20	24	21
3	23	23	25	20
4	24	22	24	22
5	22	21	25	22
6	24	20	22	19
7	23	24	23	21
8	23	22	24	22
9	22	22	22	22
10	24	23	24	24
Average	23.4	21.9	23.6	21.6

Plate 61 - Quantitative difference in the amount of nutrients before and after consumption by *A. (H.) chaliensis* sp. nov. on *C. gigantea* and *H. davisi* sp. nov. on *X. zylocarpa*

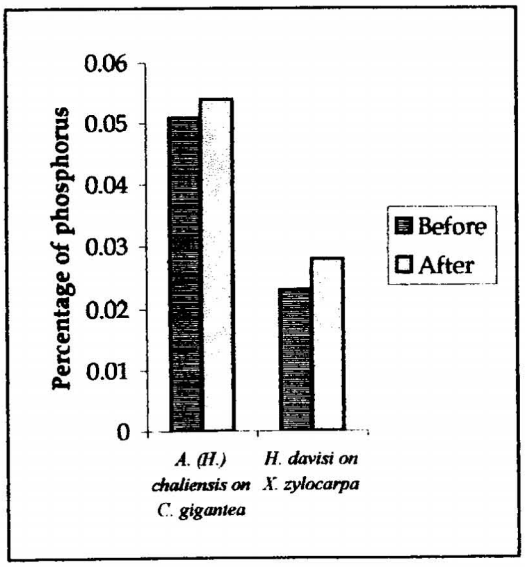
(1) Organic carbon



(2) Nitrogen



(3) Phosphorus



(4) Potassium

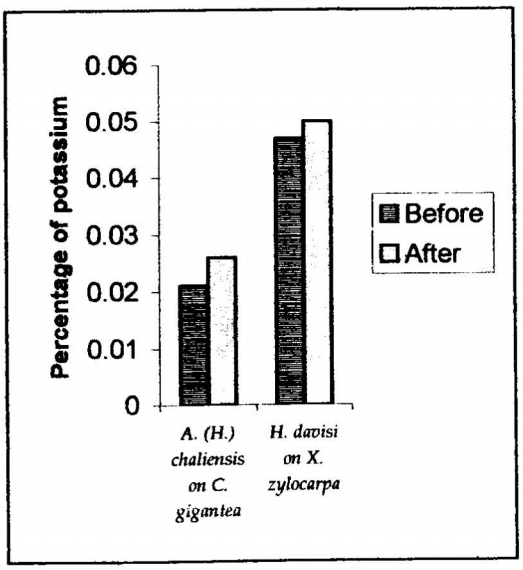


Plate 62 - Significance of nutrient release due to feeding by *A. (H.) chaliensis* sp. nov. on *C. gigantea* and *H. davisi* sp. nov. on *X. zylocarpa*

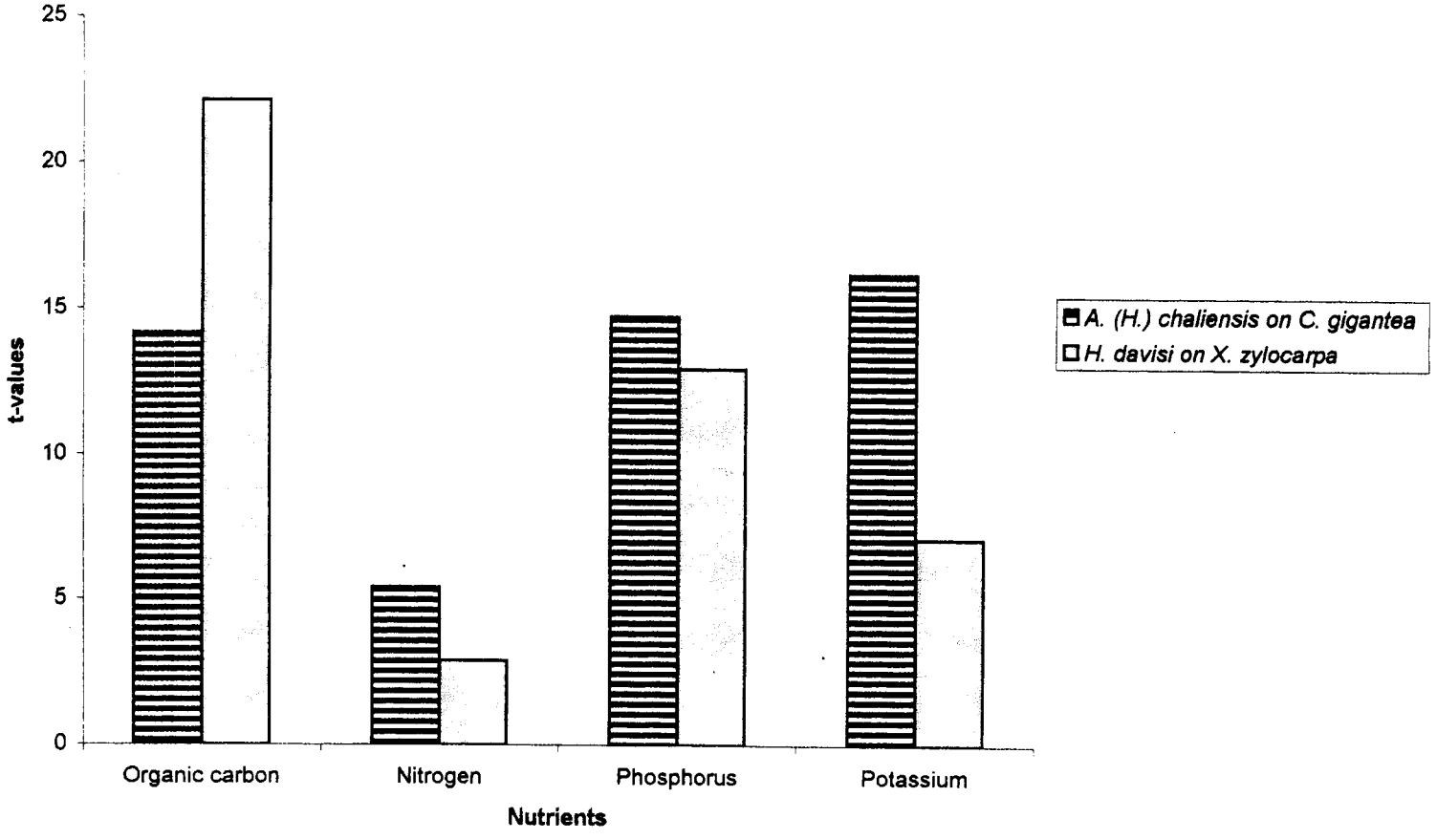


PLATE 63

Oriculture

Fig. 1 Experimental and control plants of *Vigna unguiculata* after 60 days of growth

Fig. 2 Experimental plants of *V. unguiculata* with pods

Plate 64 - Height (in cm) of *V. unguiculata* after 60 days of growth in test and control plants in Experiments I and II

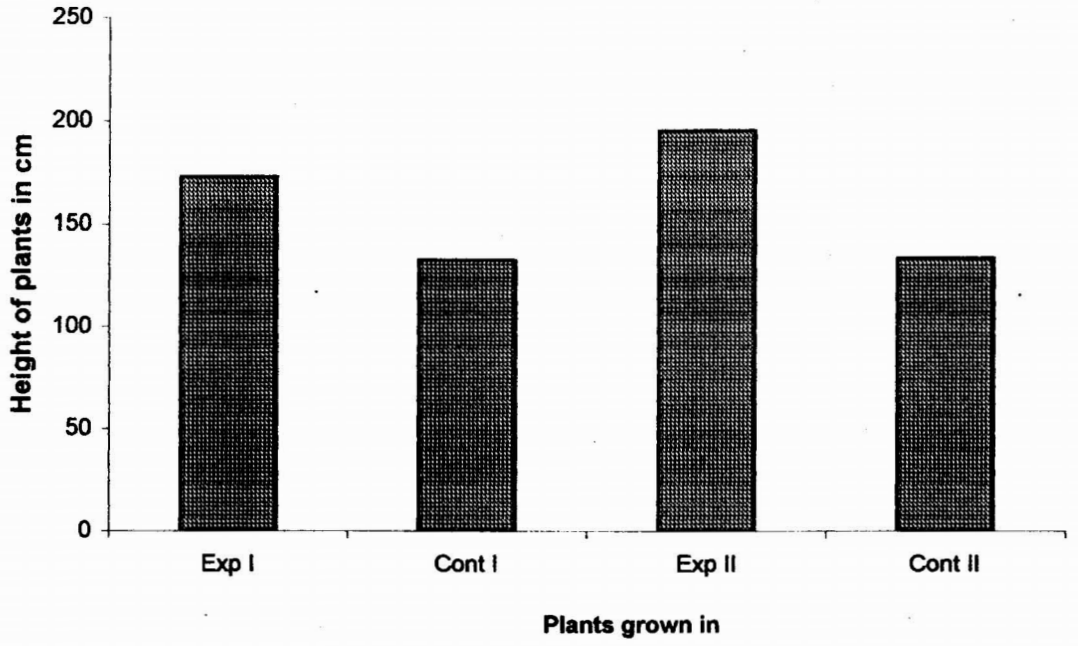
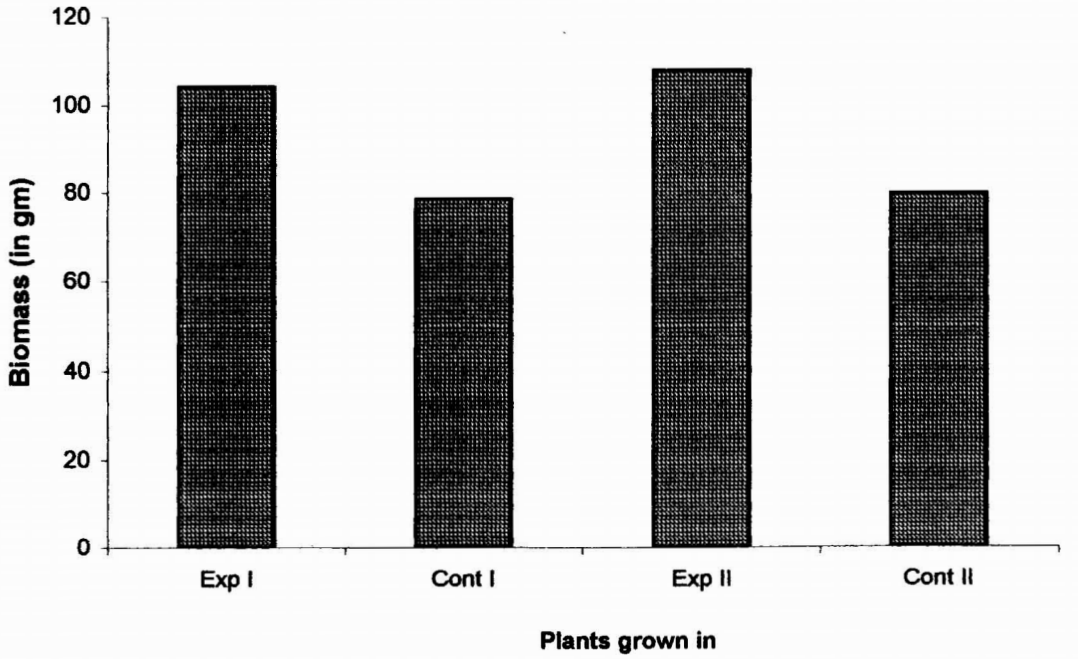


Plate 65 - Biomass (in gm) of *V. unguiculata* after 60 days of growth in test and control plants in Experiments I and II



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PART II
DISCUSSION

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

DISCUSSION

The digestive process taking place in the gut of any organism leads to the breakdown of complex food into simple absorbable units. This happens in the digestive tract of oribatid mites also. Normally, the highly lignified and cellulose containing plant and other organic litter consumed by them get degraded by the action of cellulase enzyme in the gut (Haq and Konikkara, 1988; Haq, 1996; Ramani and Haq, 2001). After absorption and assimilation, the undigested remnants are released into the environment as faecal pellets. These faecal pellets substantially help to increase the nutrient pool of the soil ecosystem. This can be established repeatedly in the case of several species of orbatid mites studied currently. This warrants the extreme necessity of introducing oribatid mites in agriculture for better crop improvement. Increase in chemical composition of litter components after consumption by oribatid mites can be taken as an index of oribatid potential in bioprocessing of organic residues (Haq, 1996).

Chemical analysis conducted in the present study showed a general increase in the concentration of all the four elements tested viz., organic carbon, nitrogen, phosphorus, and potassium in litter samples of *C. gigantea* and *X. zylocarpa* after consumption by the phthiracarid mite, *A. (H.) chaliensis* and the lohmanniid mite, *H. davisi*. This established the potential of oribatid mites in the enhancement of soil fertility through enzymatic breakdown of litter components in their gut and subsequent release of nutrients to the environment. Earlier information regarding

this crucial role played by oribatid mites is rather scanty. Yet a few earlier workers (Schuster, 1956; Wallwork, 1958; Hartenstein, 1962; Hays, 1963; Berthet, 1964; Luxton, 1966; Kowl, 1969; Kowal and Crossley, 1971; Hammer, 1972) had stressed the bioprocessing ability of oribatid mites. Relevance of these mites in the recycling of a few essential nutrients like calcium and potassium has been brought to light through some isolated studies (Cornaby *et al.* 1975; Gist and Crossley, 1975; Werner and Dindal, 1987). Norton (1984) reported that feeding by oribatid mites leads to an increase in nitrogen content of organic litter. Haq (1996) conducted quantitative analysis of certain macro and micronutrients in selected items of plant litter after consumption by oribatid mites and reported a general increase in concentration of nitrogen and phosphorus in all the materials tested. Ramani and Haq (2001) showed that feeding activity of *H. rimosus* and *Lohmannia* sp. increased the nutrient status of the litter of *A. integrifolia*. The above authors found that both macro and micronutrients increased. These observations in the light of the present findings signify the utilization of oribatid mites in promoting soil productivity.

Results of the present study showed that food materials taken by the oribatid mites were subjected to enzymatic breakdown in their gut. This led to the release of nutrients from the bound state, enabling utilization of the same by mites for their metabolic activities after assimilation. Undigested materials ejected as faecal pellets will be enriched with the unassimilated nutrients, thereby increasing the nutrient value of soil. These faecal pellets readily mix with soil and

provide an appropriate medium for further breakdown by microbial action. Thus the combined action of oribatid mites and soil microbes make the nutrients available in soil for utilization by members of other trophic levels. Therefore, it is quite obvious that these mites are actively involved in nutrient release , one of the crucial steps in the process of nutrient cycling.

From the above, it is clear that soil dwelling oribatid mites are instrumental in the bioprocessing of organic residues and mineralisation, thereby playing a vital role in nutrient cycling and energy flow. It appears that nutritional diversity of oribatid mites is the key factor which make them the pioneer in the process of biodegrdation and nutrient release.

In the present study, the practical application of the above aspect of oribatid activity was tested experimentally by a novel method of cultivation designated as 'oriculture'. The study showed that after 60 days of growth, plants grown in litter inoculated with *A. (H.) chaliensis* in Experiment I were taller on an average by 40.6 cm compared to their controls. Similarly plants grown in litter containing *H. davisi* in Experiment II exhibited an average increase of 58.6 cm in height compared to their controls. When the biomass of plants after 60 days of growth was assessed, plants grown in Experiment I weighed 25.5 gm more than their controls while plants in Experiment II weighed 28.1 gm more than their respective control. Significance of this difference in biomass was tested statistically by applying 't' test. The 't' value in the case of Experiment I was 3.19 and that of Experiment II was 3.14. Both

these values were greater than the table value for 't' at the same level which was equal to 2.262. This showed that the increase in biomass exhibited by plants grown in oriculture was significant.

The study also showed that plants grown in soils enriched with oribatid mites exhibited early flowering. In Experiment I, plants produced flowers 16.6 days before their controls while plants in Experiment II flowered 17.3 days before their controls. Bernier (1988) proposed the nutrient diversion theory to explain the process of flowering in plants. Flowering is a highly complex physiological process which requires more energy and nutrients than that is required for ordinary plant growth. When plants are induced for flowering the shoot apex resists a higher concentration of assimilates than the non flowering plants. Conversely when plant receives more nutrients from soil earlier flowering is induced. Thus, it appears that plants produce flower when the nutrient level in the plant body is higher than that is needed for normal growth. When nutrients are abundant in the medium in which plants are grown, they absorb the same for growth and the nutrient absorbed in excess of ordinary plant growth is diverted for flowering process. Thus, there is a threshold of nutrient level above which alone flowering occurs. It is clear from the present study that plants grown in oriculture beds reached this threshold level much earlier than their respective controls inducing early flowering. On the contrary, plants grown as controls did not have this advantage and had to absorb nutrients for a longer period to reach the threshold level required for

flowering. This is a positive indication of oribatid potential indicating early flowering of plants through improving nutrient content of soil.

Fruit production in any plant is influenced by nutrient composition of the soil in which the plant is growing. This is reflected in the quality and quantity of fruits and seeds produced. Observations made in the present study showed that average length of pod in Experiment I was 23.4 cm while that of the control was 21.9 cm. In Experiment II, the same was 23.6 cm and that of the respective control was 21 cm. The study thus showed that both the experimental plants produced longer pods when compared to their controls. Plants grown in oriculture beds appeared to have the advantage of readily available nutrients released by oribatid feeding activity. This induced the production of longer pods by the experimental plants.

The foregoing account clearly indicates the positive role played by oribatid mites in the release of nutrients into soil. Gasdorf and Goodnight (1963) demonstrated substantial decrease in cellulose in the faeces of oribatid mites. This can be due to the digestive action taking place in the gut of these mites with the help of cellulose digesting enzymes (Haq, 1996; Ramani and Haq, 2001). But Schuster (1956) observed that most of the food intake by oribatid mite leaves the gut without much change. But the present study showed that food taken by the oribatid mites leaves the gut greatly altered after digestion and the faecal pellets contain increased amount of carbon, nitrogen, phosphorus and potassium. This is a clear indication of bioprocessing ability of oribatid mites.

The study thus helped to establish the fact that oribatid mites as an important link in the detritus food chain, play an active role in the breakdown of organic litter. Their importance in humification process, nutrient cycling and energy flow has been stressed by earlier workers (Wallwork, 1958; Hartenstein, 1962; Hayes, 1963; Luxton, 1975; Haq, 1996, 2002; Jain and Neha, 2003; Ramani and Haq, 2001). The large quantities of litter that accumulate on soil surface become an integral part of the soil ecosystem through the effective involvement of microbes and other microarthropods, especially mites (Fujikawa, 1970, 1972; Dinsdale, 1974; Tadros, 1976; Ramani and Haq, 1990; Haq, 1994; Hansen, 1999). The mites thus act as excellent biodegraders of plant and other organic litter in the soil. The soil is thus made organically rich with increased fertility and hence agricultural productivity. Their role in transformation of energy from one trophic level to the next make it available to a new set of crop plants. This is an important aspect of oribatid activity to be exploited particularly by countries whose economy is mainly agrobased. India being an agricultural country, usage of oribatid potential in the promotion of soil fertility and productivity deserves special recognition. It is here that the novel method of cultivation, viz., 'Oriculture Technology' developed in the present study, acquires significance. 'Oriculture' as a new technological approach to better soil productivity can greatly accelerate agricultural output as was evidenced in the present study. This in turn will lead to a more effective utilization of natural resources without affecting the ecological balance in nature.

Agriculturists, all over the world, are trying to evolve better methods of cultivation by implementing different patterns of natural farming practices. 'Oriculture Technology' can be high lighted as the most appropriate natural farming method that can be practiced in any type of soil as natural ecosystems always contain sufficient number of oribatid mites. This technology will also be an answer to the various problems faced by ordinary farmers. Nowadays cost of agricultural production has increased many fold due to the increase in cost of fertilizers. In 'Oriculture Technology' there is no necessity of frequent application of other fertilizers, particularly artificial fertilizers. This greatly reduces the cost of agricultural production. Apart from that, this method is environment friendly, as there is no addition of chemicals into the soil. This reduces soil pollution which otherwise occurs as a result of usage of artificial fertilizers. The technique is simple and can be practiced without much difficulty. Ordinary farmers without much scientific or technical expertise can easily be trained in oricultural practices.

Another positive aspect of 'Oriculture Technology' lies in its possibility to provide jobs for enterprising youth. 'Oriculture Technology' involve utilisation of large numbers of oribatid mites in bioprocessing of organic litter. Farmers must be provided with sufficient cultures of oribatid mites to initiate 'Oriculture Technology'. This involves large scale production of oribatid mites which are involved in the biodegredation of organic litter. For this, coaching must be given to interested youth about the most important taxonomic groups of these mites and their rearing procedures. Knowledge and availability of experts in the field may

properly be provided so that they can set up "Oribatid Mite Breeding Centres" from where the oribatid mites can be made available to farmers at reasonable cost. This can be taken up as an extension activity of universities and laboratories involved in acarological and soil biological programmes.

'Oriculture Technology' can thus be treated as the modern method of agriculture with minimum cost of production and maximum yield in a most suitable ecofriendly atmosphere. Hence it is strongly recommended that 'Oriculture Technology' may be practised as the new millennium way of agriculture in the form of natural farming. 'Oriculture Technology' thus offers a most convenient, cost effective and ecofriendly method of agriculture that can be taken up by countries like India whose economy is agrobased.

PART II
SUMMARY

Alphonsa Xavier “Bioprocessing of organic residues through oriculture technology ” Thesis. Department of Zoology, University of Calicut, 2004

Chapter XVIII

SUMMARY

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All living matter, microbes, plants and animals depend on the soil for their sustenance. Soil forms their fundamental substrate and acts as the reservoir for all natural elements. This is especially true with the case of materials of autotrophic origin which are being added to the soil in the form of mature plant structural components. These structural components form the organic litter which are rich sources of nutrients in a trapped form. It is highly essential that these trapped nutrients should be returned to the environment to re-enter the biogeochemical cycles to make it available for re-utilization by autotrophic system. This ecological necessity is satisfied by the operation of the detritus food chain initiated by the detritivorous faunal components, particularly the microarthropod community. Oribatid mites represent the most conspicuous soil arthropods involved in this decomposer food web. They are the sole arachnid members contributing to soil structure. Their microscopic size make their contribution to decomposition process insignificant when compared to that of annelids and other arthropods. But they have surpassed this through their abundance and adaptability. Their unique adaptive strategies have helped them to invade and establish almost all habitats which appear formidable to other faunal elements with related nutritional habits. It was this aspect of oribatid community which inspired to take up the present research work.

The diverse feeding trends exhibited by oribatid mites enable them to play a significant role in bioprocessing of organic litter through their mechanical breakdown, microbial inoculation and also stimulation of microflora. An understanding of the importance of these mites in nutrient cycling and energy flow have raised their status to a great extent. In the present work an attempt has been made to identify the important taxonomic groups of oribatid mites which play a significant role in the decomposition process, their nutritional and reproductive strategies and efficiency in improving soil fertility and productivity.

The results of the work are presented in two parts. The first part includes the results of the survey conducted to enumerate and identify oribatid mites collected during the present study. The second part is devoted to biological aspects of oribatid mites especially their feeding habits which form the basis of organic decomposition. Apart from this, breeding biology of a few representatives with proved potential in bioprocessing of organic residues, particularly the plant litter was also carried out in order to supplement knowledge on their reproductive strategies and number of annual generations to get an idea of their population density in the field. Potential of oribatid mites in bioprocessing of organic litter was assessed by estimating the nutrient content of selected food items before and after consumption by these mites and testing its influence on plant growth through oriculture technology.

For the survey, four different localities situated rather close to each other but with totally different floral composition were selected to collect

the oribatid mites. Soil and litter samples collected from these study sites were subjected to extraction through modified Berlese-Tullgren funnels to separate the oribatid mites. Mites were collected in preserved condition for taxonomic studies and in live condition for biological studies. Preserved specimens were cleared in a mixture of lactic acid and alcohol in 1:1 ratio and mounted in Hoyer's medium and identified. Drawings of species involved in bioprocessing of plant residues were further carried out in detail with the help of microscope with attached Camera Lucida.

A large number of oribatid mites were collected of which 58 species belonging to 21 genera, 11 families and nine superfamilies alone were considered in the present study. 65.5% of the oribatid mites identified belonged to Oribatei Superiores and 34.5% to Oribatei Inferiores. Oribatei Inferiores consisted of four families viz., Apoplophoridae, Phthiracaridae, Lohmanniidae and Trhypochthoniidae. Family Lohmanniidae consisting of eight genera and 25 species had the maximum species diversity followed by Phthiracaridae with three genera and eight species, Trhypochthoniidae with two genera and four species and Apoplophoridae with a single genus and a single species. Oribatei Superiores consisted of seven families viz., Basilobelbidae, Otocepheidae, Oppiidae, Scheloribatidae, Haplozetidae, Xylobatidae and Galumnidae. Each of these families were represented by a single genus. Scheloribatidae and Galumnidae had the maximum species diversity of seven species followed by Oppiidae with two species and the remaining four families with a single species each. The study also helped to erect 15 new species.

The numerical abundance and species diversity of oribatid mites are controlled to a certain extent by climatic factors like temperature and rainfall. Hence population density of these mites was studied in relation to the above factors. For this regular monthly samples were collected from the four sites mentioned. Data relating to species diversity, seasonal fluctuation in population density, temperature and rainfall during the study period were collected and interpreted on statistical grounds. Maximum number of oribatid mites was collected in the month of June which received the maximum rainfall and experienced the lowest temperature. Minimum number of oribatid mites was collected in March which received the minimum rainfall and experienced the highest temperature. The population density of oribatid mites reached a peak during monsoon season and declined drastically during summer. The study thus helped to establish a positive correlation between population density and rainfall and a negative correlation between density and temperature.

The occurrence of oribatid mites in a multitude of micro-conditions of the soil is mainly determined by their ability to consume the available food items present in natural habitats. This has led to the development of a variety of feeding reactions among oribatid mites. To ascertain the food preference of field collected oribatid mites, gut content analysis of 31 species was performed. Food boli and gut contents of live mites were dissected out on microscopic sides, spread out evenly in glycerine and observed under research microscope. Appropriate stains were applied for

better observation. Gut contents of 21 species exhibited the presence of particles of higher plant origin in different stages of digestion. Gut of four species contained fungal hyphae, spores and bacteria while six species revealed the presence of both lower and higher plant components. The study thus helped to categorise the first group of mites as macrophytophages which subsisted on higher plant elements, the second group as microphytophages which depended on lower plant elements and the third as panphytophages which fed on both. It was seen that all the macrophytophages belonged to Oribatei Inferiores, five species of which belonged to the family Phthriracaridae and 16 to the family Lohmanniidae. Of the four microphytophagous species, one species viz., *Apoplophora pantotrema* belonged to Oribatei Inferiores and three species viz., *Basilobelba retiarius, Oppia kunhnelti* and *Pelokylla malabarica* to Oribatei Superiores. Of the six panphytophagous species, *Allonothrus giganticus* and *Archegozetes longisetosus* belonged to Oribatei Inferiores and four species viz., *Megalatocephaus glabrus, Scheloribates decarinatus, Xylobates seminudus* and *Galumna flabellifera* belonged to Oribatei Superiores.

Feeding responses of oribatid mites to higher plant elements were tested in the laboratory by conducting feeding experiments. The 21 species of macrophytophagous and six species of panphytophagous oribatid mites identified in gut content analysis were reared in the laboratory by offering them leaves and wood of 11 different species of higher plants and drift wood. The study showed that all the members of the family Phthiracaridae were primarily wood eaters while members of the family Lohmanniidae

were leaf eaters except *Heptacarus indicus*. This species closely resembled phthiracarid mites in its feeding behaviour with a preference to drift wood. Feeding activity of these two groups of mites led to the production of tunnels and cavities within the wood leading to its shredding and skeletonisation of leaf. Feeding activity of panphytophagous species accelerated the above reaction finally leading to the complete break down of the higher plant elements. The present study thus established the capacity of oribatid mites in bringing about decomposition of higher plant elements.

Analysis of the gnathal appendages showed the individual modification of chelicera, rutellum and pedipalp to suit the particular feeding habit. Macrophytophagous forms had thick, well developed and sclerotised rutellum and chelicerae with prominent teeth. Microphytophagous froms had long and thin rutellum and chelicerae suitable for feeding on bacteria, fungi etc. Panphytophagous forms had an intermediate type of gnathal structures allowing to feed on a multitude of food materials. The study thus showed that the major feeding categories of oribatid mites possessed appropriate type of gnathal appendages which allowed them to attack a variety of food resources available in natural ecosystem. This was important in their survival and establishment in various habitats.

Population density of any organism depend greatly on their reproductive potential. Since oribatid mites form a major component of soil mesofauna, an understanding of their reproductive strategies is highly

essential. Hence in the present work, breeding biology of three species of macrophyotphagous oribatid mites viz., *Atropacarus* (*Hoplophorella*) *chaliensis*, *Haplacarus davisi* and *Heptacarus indicus* was worked out. The first species belonged to the family Phthiracaridae and the last two to the family Lohmanniidae. Live adults were reared in specially constructed culture vessels containing Plaster of Paris-charcoal base and offering them their preferred food substances. Observations were made on oviposition, hatching, active and quiescent phases, moulting, and duration of each phase. Morphological peculiarities of each stage was studied with appropriate illustrations. In general, all the three species studied passed through five different active phases in their life cycles. The egg after incubation hatched out into a hexapod larva which underwent four successive moults releasing protonymph, deutonymph, tritonymph and adult respectively after each moult. Each active phase was followed by an inactive quiescent phase leading to moulting and emergence of next higher phase. The duration of development varied with individual species. *A. (H.) chaliensis* took 81-89 days, *H. davisi* 130-144 days and *H. indicus* 142-154 days to complete development from egg to adult. The study thus showed that the duration of development of the two lohmanniid mites was longer than that of the phthiracarid mite. This long duration of development in lohmanniid species led to a lesser number of annual generations. The study also revealed that irrespective of their taxonomic position, different oribatid species followed the same pattern of development with species specific modifications. It was also noticed that immature stages of all the

species studied had higher food intake compared to the adults which reflects their better bioprocessing efficiency.

Macrophytophagous oribatid mites consume large quantities of higher plant elements as food leading to their chemical breakdown and release of the same as faecal pellets after digestion and absorption. This process of biodegradation leads to enrichment of soil nutrients, fertility and productivity. In the current study, this was assessed chemically by analysing the nutrient content of organic litter before and after consumption by oribatid mites. Quantitative evaluation of four major nutrients viz., organic carbon, nitrogen, phosphorus and potassium present in two food items before and after consumption by oribatid mites was carried out. The food items selected were woody and root tissues of the weed plant *Calotropis gigantea* from Chaliyam beach and leaves of *Xylea zylocarpa* from Kakkanchery. The former item was consumed by the phthiracarid mite *A. (H.) chaliensis* and the latter by the lohmanniid mite, *H. davisi*. In the case of both the food items, remarkable increase in the content of all the four nutrient elements was noticed after consumption by oribatid mites. This substantiated the potential of oribatid mites in the release of bound nutrients from plant structural polysaccharides to soil, enhancing soil fertility and productivity.

The bioprocessing ability of oribatid mites can be exploited suitably to meet our growing needs of agricultural production. In the present study this was tested by developing a novel method of agriculture designated as 'oriculture'. Oriculture involved the use of macrophytophagous oribatid

mites in enriching soil fertility through their feeding activity and cultivating vegetables with fast growth in this nutrient enriched soil. Into sterilized soil containing wood and root of *C. gigantea* introduced the phthiracarid mite *A. (H.) chaliensis* and into leaf litter of *X. zylocarpa* the lohmanniid mite *H. davisi*. After 10 months, seeds of the common cowpea *Vigna unguiculata* was sown in these soil samples and their growth, development, flowering and fruiting were studied with appropriate controls. Growth in terms of height of the plant, biomass, time taken for appearance of flowers and length of the pods were assessed and statistically analysed. It was found that plants in oriculture exhibited faster growth, higher biomass, early flowering and produced slightly longer pods, when compared with their controls. The study thus revealed the influence of oribatid mites in improving soil conditions leading to enhanced productivity.

The above results emphasize the necessity of developing a systematic approach for harnessing the bioprocessing ability of oribatid mites. The current study proved that oriculture is the most effective way of utilizing this aspect of oribatid behaviour. Application of Oriculture technology will be a boost to our agricultural sector and a novel method for restoring soil health. Oriculture when introduced in the proper way will definitely reduce the cost of agricultural production as the requirement of artificial fertilizers will be much less than in the conventional types. Pollution due to application of chemical fertilizers is also reduced to the minimum. The vertical and horizontal migrations undertaken by oribatid

mites will increase soil porosity and aeration. Hence oriculture technology will be a most ecofriendly method of agriculture. Moreover this method does not require any technical expertise and as such can be practised by ordinary farmers. Since different species of oribatid mites occur in sufficient numbers in almost all types of soil and litter components, there is no limitation for the application of oriculture technology. Above all, this technology opens up new avenues in creating jobs for the unemployed youth. Knowledge of experts in the field can be utilised in giving training to enterprising youth regarding a preliminary understanding about oribatid mites, the important taxonomic groups involved in bioprocessing of organic litter, their feeding and breeding and large scale culture. This may help them to set up 'Oribatid Mite Breeding Centres' from where the oribatid mites for oriculture can be distributed to farmers at a reasonable cost. Serious extension activities may be undertaken by leading laboratories dealing in acarological research to introduce oriculture to ordinary farmers and agriculturists. India being primarily an agricultural country, steps should be taken to popularise 'Oriculture Technology' as a novel national programme. 'Oriculture Technology' thus may be considered as the modern agricultural method of the new millennium.

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