BIONOMICS OF *Pareuchaetes pseudoinsulata* REGO BARROS (LEPIDOPTERA: ARCTIIDAE) AND ITS INTERACTION WITH THE SIAM WEED *Chromolaena odorata* KING AND ROBINSON (ASTERACEAE)

By

K. R. LYLA

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agricultural Entomology
COLLEGE OF HORTICULTURE
Vellanikkara - Thrissur 680654

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DECLARATION

I hereby declare that this thesis entitled "**Bionomics of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) and its interaction with the Siam Weed *Chromoleana odorata* King and Robinson (Asteraceae)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title of any other University or Society

Vellanikkara

Lyla, K R.

DR C C ABRAHAM
Associate Dean
College of Horticulture

Vellanikkara

CERTIFICATE

Certified that this thesis entitled "**Bionomics of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera Arctiidae) and its interaction with the Siam Weed *Chromoleana odorata* King and Robinson (Asteraceae)** " is a record of research work done independently by **Smt Lyla, K R** , under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her

20.6.95

C C ABRAHAM
Chairman
Advisory Committee

DR C C ABRAHAM
Associate Dean
College of Horticulture

Vellanikkara

CERTIFICATE

Certified that this thesis entitled "**Bionomics of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera Arctiidae) and its interaction with the Siam Weed *Chromoleana odorata* King and Robinson (Asteraceae)** " is a record of research work done independently by **Smt Lyla, K R** , under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her

20/6/95

C C ABRAHAM
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned members of the advisory committee of **Smt Lyla,K R.** a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in **Agricultural Entomology**, agree that the thesis entitled "**Bionomics of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera.Arctiidae) and its interaction with the Siam Weed *Chromoleana odorata* King and Robinson (Asteraceae)** " may be submitted by Smt.Lyla,K R. in partial fulfilment of the requirement for the degree

Dr C C Abraham
Associate Dean
College of Horticulture
Vellanikkara
(Chairman)

Dr.P.J.Joy
Professor and Head
Department of Agricultural Entomology
College of Horticulture
Vellanikkara
(Member)

Dr M J Thomas
Associate Director
Kerala Agricultural University
Vellanikkara
(Member)

Dr A I.Jose
Professor and Head
Department of Soil Science and Agricultural Chemistry
College of Horticulture
Vellanikkara
(Member)

Prof.P.V. Prabhakaran
Professor and Head
Department of Agricultural Statistics
College of Horticulture
Vellanikkara
(Member)

APPROVED BY

Dr C C ABRAHAM
Associate Dean
(Chairman)

Members

1 Dr P J JOY

2 Dr M J THOMAS

3 Dr A I JOSE

4 Prof P V PRABHAKARAN

EXTERNAL EXAMINER

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Lyla, K R

DEDICATED TO MY LATE BROTHER

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Introduction

INTRODUCTION

The neotropical Siam Weed *Chromolaena odorata* L R M King and H Robinson (Asteraceae) was introduced to Asia in mid or late 1800's The geographical distribution of the weed is limited to warm and humid tropics at latitudes between 30° N and 30° S and at an altitude of upto 1000 m near the equator The plant thrives well in the regions having rainfall of around 2000 mm per annum and above and temperature ranging from 20-37°C It is a herbaceous perennial growing up to a height of three metres in open situations and up to eight metres in deep interior forests It has recently become established in several parts of Asia and West Central and South Africa as a major aggressive weed This weed species has become a menace in several parts of India, particularly in the plantations of the Assam, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal States It grows as an aggressive colonizer in diverse habitats such as areas cleared for developing new plantations, nurseries, open plantations, agricultural fields, pasture lands, fallow lands, waste lands, road sides, river banks, thatched roofs, slashy and burnt areas and even rocky patches of land (Ambika and Jayachandra, 1980b) In Kerala, *C odorata* enjoys a wide distribution in all the districts and it occurs from the hilly terrain right up to coastal strips of land Being an invasive colonizer of hardy nature, the weed has become a severe threat to forestry, pasture as well as to plantation crops such as rubber, coffee, coconut, cocoa and cashew

The capacity of the weed for rapid dissemination through seeds is remarkable Once an area becomes infested the weed is difficult to be controlled, because of the prolificity of seed production Different methods of control such as

mechanical, cultural, chemical and biological are being adopted for the management of this troublesome weed Mechanical control is labour intensive and, therefore, very expensive and this method can be successful only if carried out at frequent intervals Cultural control is relatively long lasting, provided that a mechanical or chemical control operation preceeds the cultural operations Chemical control is effective but has the disadvantage of high costs and environmental pollution hazards According to Cock and Holloway (1982) *C odorata* is a good candidate for biologi cal control by the introduction of natural enemy complex The biological methods are safer, self perpetuating and economical and hence deserves a prominent place in the contri ol strategies An integrated management strategy with a strong component of biological control deserves special consideration for the control of this weed

Intensive surveys of the natural enemy complex of *C odorata* were carried out in South America (Cruttwell, 1969, 1971 and 1974) and in Trinidad (Crutwell, 1972 and 1974) *Pareuchaetes pseudoinsulata* Rego Barros (= *Ammalo insulata* Walk) (Arctiidae Lepidoptera) and *Apion brunneonigrum* Begum - Billecocq (Apionidae Coleoptera) have been recommended as promising biocontrol agents of *C odorata* (Bennett and Cruttwell, 1973) *A brunneonigrum* adult weevils received from CIBC, Trinidad through National Centre for Integrated Pest Management (NCIPM), Bangalore were multiplied and field liberated at Vellanikkara, but no establishment took place (Joy *et al* , 1993) *P pseudoinsulata* was introduced to India by the CIBC in the early 1970's (Julien, 1987) following the request of the Karnataka Agricultural Department to explore the biological control of the weed in coffee, citrus and cardamom plantations in Kodagu district and conducted host specificity tests with 85 species of plants representing 46 families (Sankaran and Sugathan, 1974) Later, during 1981 *P pseudoinsulata* brought here through

CIBC from Horticultural Experiment Station, Chettalli, Kodagu were multiplied and released without any success The second consignment of *P pseudoinsulata* caterpillars of the Sri Lankan strain received from CIBC, Bangalore during July, 1982 were also mass multiplied and released In spite of extensive field releases, the overall performance of the insect was unsatisfactory The constraints to the successful field establishment of the caterpillar in newly introduced areas are not fully understood The occurrence of the nuclear polyhedrosis virus infection and predation of the larvae by birds and ants have been reported to cause decline in their field population after releases The disease infection could be controlled by strict enforcement of sterile condition in lab cultures by rigorous elimination of sources of infection from cadavers The field release of *P pseudoinsulata* eggs on the ventral sides of the lamina will protect the emerging larvae from predators Mumappan and Marutani (1988c) reported that the *C odorata* plants showed possible evasive tactics against insect by a general trend of partial chlorosis in the leaves The influence of environmental conditions particularly temperature and humidity on the biotic potential of the insect is a factor of considerable importance that can regulate the multiplication of the insect

The present investigation was taken up to study the bionomics, feeding habits, natural enemies, factors affecting fecundity and fertility of the insect as well as its interaction with the host weed in Kerala, in order to develop suitable methods to enhance the efficiency of *P pseudoinsulata* as a biocontrol agent against *C odorata*

Review of Literature

REVIEW OF LITERATURE

Popularly called Siam weed, the perennial shrub *C odorata* is a native to Central and South America It has recently become established in several parts of Asia and West, Central and South Africa Literature on the botany, systematic posi tion, economic importance, methods of control, possibilities of biocontrol and natural enemies with special reference to use of *P pseudoinsulata* are briefly re viewed here

2 1 Growth habit and Phenology

The Siam weed *C odorata* (Asteraceae) is a perennial shrub growing to a height of three metres in open situations and up to eight metres in the deep interior forests where it assumes a scrambling habit (Bennett and Rao, 1968, Rai, 1976, Ambika and Jayachandra, 1980a) The botany and the phenology of the species have been described by King and Robinson (1970), Salgado (1972) and Rai (1976)

2 2 Origin, distribution and spread

The Siam weed is native to West Indies and Central and Tropical South America (Cruttwell, 1968) The distribution of *Chromolaena* is limited to warm and humid tropical regions, latitudes between 30°N and S and upto altitudes of about 1000 m (Ambika and Jayachandra, 1990) According to them, it thrives very well in regions having annual rainfall of 2000 mm and above and temperature ranging from 20 to 37°C Precipitation, temperature and light intensity control the distribution and spread of this species

This weed was accidently introduced from the Caribbean in the ballast of cargo boats into Singapore from where it spread into the humid tropical regions of the South and Southeast Asia (Biswas, 1934) But the presence of the weed in India was recorded as early as in 1903 by Prain (1903 and 1906) who stated that it used to be cultivated occasionally in ornamental gardens in Central and East Bengal and around Calcutta Rao (1920) was the first to report the rapid spread of this weed in most areas of Assam and Bengal in Eastern India According to him it had spread from Singapore through Malaysia, Thailand and Burma It was introduced to South western part from Eastern India during the second world war (Bennett and Rao, 1968) Grierson (1980) reported this as a dangerous weed in Ceylon (Sri Lanka) The weed was introduced into Nigeria in 1937 through the import of contaminated *Gmelina arborea* Roxb seeds from Ceylon from where it then spread to Ghana, Cameroon, Ivory Coast and South Africa (Ivens, 1974)

Chromolaena was introduced to Guam in early 1960's (Seibert, 1989) and it became established in the neighbouring islands of Rota, Tinian, Aguijan and Saipan in the Northern Mariana Islands Cruttwell (1988) stated that much of the spread took place by natural progressive spread by means of wind borne seeds According to her, the extensive movements of people, machinery and materials during the second world war caused extensive spread of the weed to newer areas By the late 1960's *C odorata* was a major weed in most parts of Southeast Asia from Mauritius, the South and West Coast of India, Borneo and Java to Nepal, Bhutan and Indo China, and had since spread to the Philippines, Southern China, Southern Salawesi and the Marianas (Pancho and Plucknett, 1971)

2 3 The problem of *C. odorata*

With a very good ability to spread fast and being an aggressive colonizer in the introduced areas, the species is now a menace in India in the plantations of Assam, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal (Moni and George, 1959, Rai, 1976, Ambika and Jayachandra, 1980b) It grows as an aggressive colonizer in different habitats such as areas newly cleared for establishing new plantations, nurseries, young and open plantations, agricultural fields, pasture lands, fallow fields, waste lands, road sides, river banks, tree tops, thatched roofs, rocky areas, slash and burnt areas (Chakraborthi *et al* , 1967, Soerohaldoko, 1971, Salgado, 1972, Ivens, 1973, 1974, Rai, 1976, Mishra and Sharma, 1979, Yadav and Tripathi, 1979, Ambika and Jayachandra, 1980b) in different parts of the world

2 4 Economic importance

The weed does not cause any serious concern in its native habitat (Crut twell, 1988) But elsewhere, it is posing grave problems in the plantations of teak, rubber, coffee, softwood trees, oil palm, coconut, cashew, mango and other crops adversely affecting their growth, development and yield (Salgado, 1972, Ivens, 1973, Ambika and Jayachandra, 1980b, 1982, Muniappan and Marutani, 1988a) Agricultural crops are also affected adversely by the weed (Esuruosa, 1971, Napom peth *et al* , 1988, Mumappan and Marutani, 1988a) Serious health hazards to livestock and human beings are also reported by Soerohaldoko (1971) in parts of Bhutan, Nepal, China, Indonesia, Sri Lanka, Nigeria, Malaysia, India and in the Mariana Islands

In India, *C odorata* is a menace in plantations of teak, rubber, cardamom, arecanut, coconut, citrus and tea mainly in the States of Assam, Kerala, Karnataka (Moni and George, 1959, Rai 1976, Joy *et al* , 1979)

2 5 Control measures

Once an area become infested by the weed, it is extremely difficult to control this weed as it produces seeds prolifically (Weerakoon, 1972)

2 5 1 Mechanical control

As a method of mechanical control, Are and Folarin (1970) recommended slashing four times in an year in cocoa plantations of Nigeria Komolafe (1976) suggested a combination of slashing, ring weeding and mulching in Nigeria Olaoye (1977) found that periodic slashing brought about death of this weed Erasmus (1988) reported that the use of motorized bush cutters and tractor drawn equipment is limited because of the restricted accessibility in the areas of infestation According to Muniappan and Marutani (1991b)) mechanical control is labour intensive and provides only short term control

2 5 2 Cultural control

Salgado (1972) reported that *Tephrosia purpurea* grown as a cover crop in coconut plantations was effective in suppressing *C odorata* in the Sri Lanka *Pueraria phaseoloides* was recommended as a cover crop in rubber plantations in China (Rai, 1976) with a view to control the weed growth Castillo *et al* (1977)

found that planting *Leucaena leucocephala* in pastures reduced *C odorata* populations in the Philippines Cover crops such as *P javanica, P phaseoloides, Calopogonium caerulum, Desmodium ovafolum* and *Moghania macrophylla* were tried for suppression of *C odorata* and these were not found to be effective (Ambika and Jayachandra, 1990) Wu and Xu (1991) stated that Signal grass (*Brachiaria decumbens*) in pastures successfully competed with and reduced the incidence of *C odorata* in China

2 5 3 Chemical control

In the Philippines, Madrid (1974) found 2,4-D to be effective on young plants, but for mature stands, it had to be combined either with 2,4,5-T, Picloram or Dicamba In Indonesia, Soerjani *et al* (1975) stated that Picloram is used in plantations and MCPA and 2,4-D in low land rice fields of Java In India, George (1968) mentioned that Gramaxone at 2 5 kg/ha provided satisfactory control of the weed Rai (1976) suggested that spraying of Gramaxone @ 2 5 litres and 2,4-D sodium salt @ 2 5 kg/ha was effective in rubber plantations Pre-emergence and post-emergence herbicides such as Paraquat and paraquat based mixtures with Diuron, 2,4-D, Atrazine, Glyphosate etc were evaluated for control of *C odorata* in young cocoa and oil palm plantations of Central and West Africa (M'boob, 1991) and were found to give season long control of the weed

2 5 4 Biological control

According to Muniappan and Marutani (1991b) mechanical control is labour intensive and is not long lasting, while cultural control is long lasting However, either a mechanical or chemical control programme has to be carried out

A brief review on various sucking insects, defoliators, mites and pathogens is given below

2 5 4 1 a Sucking pests

In Trinidad, Urich (1913) reported *Tomaspis rubra* Germ (Membracidae) as a minor pest of the weed Sands (1916) found *Dysdercus delauneyi* Leth (Pyrrhocoridae) feeding on the weed in the St Vincent island As a pest of the weed in India, *D koenigii* Fabr has been recorded by several workers (Jalamkar *et al* , 1974, Prabhu and John, 1975, Lyla, 1983)

In Sumatra, *Bemisia tabaci* Gennadius (Aleyrodidae) was reported as a common pest of the weed (Vander Laan, 1940) and it was also recorded from Kerala, India (Lyla *et al* , 1987)

The weed is an alternate host plant for the mirid bug *Carvalhoia arecae* Miller which is a major pest of arecanut palms in the State of Kerala (Daniel and Premkumar, 1976)

As a serious pest of the weed *Aphis spiraecola* Patch (Aphididae) has been recorded from Assam (Dharmadhikari and Ramaseshiah, 1970), Ghana (Hall *et al* , 1972) and also in Kerala (Joy *et al* , 1979, Lyla, 1983) The aphid was severe on the weed in several parts of India (Raychaudhuri, 1973)

Aphis fabae Scopoli is recorded to infest the weed in India by Raychaudhuri (1973) and specifically in Kerala by Joy *et al* (1979) and Lyla *et al* (1987)

Raychaudhuri (1973) and Torres (1986) recorded *Aphis craccivora* Koch on the *C odorata* in India and the Philippines, respectively

Torres (1986) observed *Aphis gossypii* Glov attacking the weed in the Philippines

Peach leaf curl aphid, *Brachycaudus helichrysi* Kltb was recorded on the weed in India (Raychaudhuri, 1973) and particularly in higher elevations of Kerala (Joy *et al* , 1979, Lyla, 1983)

Other sucking pests recorded on the weed from India were *Gargara mixta* (Bukton) (Membracidae), *Kolla paulula* (Walker) (Cicadellidae), *Nirvana pallida* Melichar (Cicadellidae) and *Coptosoma feanum* Montand (Plataspididae) (Viraktamath and Muniappan, 1992)

2 5 4 1 b Defoliators

The arctiid caterpillar *P pseudoinsulata* (=*Ammalo insulata*) was reported as a defoliator of *C odorata* from several localities in Puerto Rico (Wol cott, 1948), the Neotropics (Cruttwell, 1968, 1969, Bennett and Cruttwell, 1973, Cock and Holloway, 1982 and Cock, 1984, Nigeria (Schroder, 1970, Ivens, 1974 and Akanbi, 1978), India (Giriraj and Bhat, 1970, Sankaran, 1971 and Simmonds, 1976), Sri Lanka (Kanagaratnam, 1975 and Dharmadhikari *et al* , 1977), Malaysia (Syed, 1977), Ghana (Simmonds, 1976), Guam and Mariana Islands (Seibert, 1985, 1986 and 1988, Muniappan and Marutani, 1988b and Muniappan *et al* , 1988a and 1989) and Kerala (Satheesan *et al* , 1987 and Joy *et al* , 1993) as well as the Philippines (Aterrado and Sanico, 1988)

Trichotaphe eupatoriella Nov (Gelechidae) was seen breeding on *C odorata* throughout the year (Chambers, 1872) It was also reported from Belem (Cruttwell, 1971) and the Neotropics (Cruttwell, 1973)

The beetle *A brunneonigrum* was reported from Trinidad as a pest of the seeds (Cruttwell, 1972 and 1973) Schroder (1970) and Ivens (1974) also had recorded this beetle on the weed Sugathan (1979) and Joy *et al* (1993) reported the results of studies on the evaluation of the beetle as a biocontrol agent in India

Cruttwell (1977a) and Bennett and Yaseen (1978) recorded the Pyralid *Mescinia parvula* Sch as a defoliator of the weed

Marutani and Muniappan (1990) observed extensive damage of flowers of *C odorata* by larvae of *Eucomphyla etheiella* Meyrick (Pyralidae) in Micronesia

In Natal, South Africa, another arctiid *Pareuchaetes aurata aurata* was reported on the weed (Caldwell and Kluge, 1993)

2 5 4 1 c Mites

Cruttwell (1977b) demonstrated the host specificity of eriophyid mite, *Acalitus adoratus* Keifer and recommended it as a biocontrol agent of *C odorata* The mite causes abnormal growth of the epidermal hairs on young leaves and stems (Mc Fadyen, 1991) Ooi (1992) reported that the mite *A adoratus* did not cause much damage to *C odorata* in Malaysia and neighbouring Countries

Ramani and Haq (1983) recorded Oribatid mites on the weed in Kerala Accordmg to Mumappan and Viraktamath (1986), *Calacarus* sp is highly host specific and it can be used for the biological control of *C odorata*

2 5 4 1 d Pathogens

The accidental introduction of the fungus *Cercospora eupatorii* to Australia was reported by Dodd (1961) According to him it was first recorded on *Ageratina adenophora* in Australia in an area where the tephritid gall fly *Procecidochares utilis* Stone had been established He also stated that in shaded areas, it had little effect, but in exposed areas it caused a great deal of leaf fall, particularly in dry weather Dodd concluded that it is host specific and the level of control achieved was due to the combined effect of introduced insect and fungus Several species of *Cercospora* and *Pseudocercospora* have been reported on *C odorata* and related species (Evans, 1987) Two groups of fungi, the rusts and *Cercospora* spp , show particular promise and the autoecious rust *Cionothrix praelonga* (Wint) Arthur attacks *C odorata* in the Caribbean and Venezuela and can cause conspicuous leaf lesions (Anon.,1988)

2 6 *Pareuchaetes pseudoinsulata* Rego Barros as a biocontrol agent

2 6 1 Introduction, establishment and spread of *P pseudoinsulata*

The arctiid had been introduced and mass released in Sri Lanka (Dharmadhikari *et al* , 1977), Malaysia (Syed, 1977), India and Ghana (Simmonds, 1976) and Philippines (Torres, 1986 and Aterrado, 1987) Of these introductions, it has got established only in the Sri Lanka (Kanagaratnam, 1975) Cock and Holloway (1982) recommended the insect for India and Nigeria Satheesan *et al* (1987) and Chacko and Narasimham (1988) reported the establishment of the arctiid in Kerala, Seibert (1985, 1986 and 1988) recorded it in Guam and Northern Mariana Islands Muniappan and Marutani (1988c) while describing the establishment

of *P pseudoinsulata* in the fields in Guam, Saipan, Rota and Tinian indicated that mostly a nucleus culture seemed to establish at one place and eventually it spread in expanding concentric circles until overlapping generations of the population occurred Wind, host density and light at night seemed to influence the direction and intensity of the spread

Muniappan and Marutani (1988b) reported *P pseudoinsulata* as an efficient biocontrol agent in Guam, Saipan, Rota and Tinian in America The introduction of the insect was reported by Esguerra *et al* (1991) to Pohnpei, Federated States of Micronesia and by Napompeth and Winotai (1991) to Thailand Ooi (1992) reported the introduction and establishment of the insect in Malaysia Joy *et al* (1993) reported the field establishment of the insect in Kerala However in Natal, South Africa the insect did not establish well (Kluge, 1991)

2 6 2 Host specificity tests

Based on detailed host specificity tests conducted with the arctiid, this was found suitable for the Indian conditions (Sankaran and Sugathan, 1974) Host specificity tests showed that the arctiid restricts its feeding on *C odorata* and few members of Asteraceae of the genus *Eupatorium* (Bennett and Cruttwell, 1973, Syed, 1977 and Cock, 1984) Napompeth *et al* (1988) performed host specificity tests in Thailand and confirmed and verified its safety as a biocontrol agent He found that of all the 48 species of plants in 25 families tested and screened, feeding was not observed and larvae died after two days of exposure on all test plants except *Ageratum conyzoides* L and *Ageratina adenophora* Sprengel, both members of Asteraceae Joy *et al* (1993) also reported the host specificity tests conducted in Kerala during 1983 using most of the important crop plants In all the test plants

there were no signs of feeding and the caterpillars did not survive for more than a week

2 6 3 Life cycle

Cruttwell (1968) recorded that total life-cycle of *P pseudoinsulata* in Trinidad was completed in 40-60 days, breeding being continuous throughout the year Syed (1977) studied the life-cycle at Sabah (Malaysia) and reported egg, lar val, pre-pupal, pupal and total developmental periods as 4, 17-29, 1-2, 10 12 and 32 47 days, respectively

Singh (1980) reported that the duration of egg stage was 5 to 9 days, larval stage 30 to 51, pupal stage 8 to 22 and adult 2 to 20 days Preliminary studies carried out in Kerala showed that the egg, larval and pupal periods and adult life-span range from 2 to 4 days, 13 to 16 days, 11 to 15 days and 5 to 8 days respectively and that the total life-cycle was completed in about 32 to 42 days at 30°C-32°C (Satheesan *et al* , 1987) The work conducted at the Philippines showed that the incubation period lasted for about 4 1 days, larva to pupa 19 8 days, pupa to emergence 8 8 days, adult longevity 4 1 days and the total life-cycle from egg laying to adult emergence lasted for 32 7 days (Aterrado and Sanico, 1988) Napompeth *et al* (1988) studied the life-cycle of *P pseudoinsulata* under laboratory conditions at Thailand and reported the egg, larval, pupal and adult stages ranged from 4, 15-20, 7 11 and 4-6 days respectively They found that total life-cycle averaged 50 8 $\pm$ 5 2 days and ranged from 44-64 days Muniappan *et al* (1989) observed the longevity of the moth as about 10 days at Bangalore, India According to Joy *et al* (1993) egg period was 3 to 5 days There were five larval instars and the duration of the larval instars were 3 2, 3 0, 2 8, 4 0 and 4 6 days respectively starting from the first to the

fifth The pre pupal period was around 2 4 days and pupal period 9 8 days The moths lived for 3 8 days

2 6 4 Biology and biometrics

The biology of *P pseudoinsulata* in Trinidad, Sabah (Malaysia), Guam (S America) and Bangalore (India) have been studied by Bennett and Cruttwell (1973), Syed (1977), Seibert (1985) and Muniappan *et al* (1988b) respectively

2 6 4 1 Egg

Eggs are laid in groups and they are creamy white in colour (Satheesan *et al* , 1987) Muniappan *et al* (1989) observed that eggs are laid in batches and glued to the lower surface of the host leaves and they are yellowish, dome shaped and 0 76 to 0 83 mm in diameter the average being 0 82 mm They stated that the eggs turned dark brown at the upper parts on the day of hatching because of the darkening of the head of the caterpillar underneath the chorion

2 6 4 2 Larva

Most caterpillars crawl down from the plants at sunrise and hide in debris and dried leaves beneath the plant (Bennett and Cruttwell, 1973) Larvae preferred shaded niches during hot and humid weather condition and were more active during night (Satheesan *et al* , 1987)

Accordmg to Syed (1977) all males and some females at Sabah had five larval instars, while some females had six

2 6 4 3 Pupa

Pupation mainly occurred at the base of the plant within a loosely spun silken cocoon constructed out of larval setae, leaf particles and other debris (Cruttwell, 1968 and Satheesan *et al* , 1987)

2 6 4 4 Adult

Emergence of moth took place at midnight in Guam (Mumappan *et al* , 1989) and it took place between 5 00 and 6 30 pm in the Philippines (Torres *et al* , 1991) According to Seibert (1989), the adults are poor flyers

2 6 4 4 a Mating behaviour

Moths mated around 0600 hours and the courtship lasted for 1 2 hours (Muniappan *et al* , 1989)

Torres *et al* (1991) recorded the courtship behaviour in detail The activity of adult is affected by light and when the observation cage was exposed to light, the moths remained motionless during the day and night and there was no mating within a 24 hour period When a male comes within 3 to 4 cm near female, it partially raises their wings and after several up and down movements within the cage, male make one, two or several circular movements around female within a radial distance of about 2 to 6 cm Sometimes, male may move away and find another female to chase in the same way, or may approach the same female and instantly copulate The female raises the wings when the male approaches, the male positions itself under the wings of female and then suddenly turns back with organs already inserted within two seconds Unless disturbed, most pairs of adults were

observed to remain in copulation for about 1 5 to 3 5 hours A few would exceed this duration and in several cases the mating pairs did not separate from each other even until death

2 6 4 4 b Fecundity

According to Cruttwell (1968), *P pseudoinsulata* laid 50 to 180 eggs in groups on the underside of the leaves and in the wet season, moths laid 150 to 250 eggs, the maximum being 580 A single female laid 120-299 eggs during its life-period, under conditions prevailing in Kerala (Satheesan *et al* , 1987) Mumappan *et al* (1988a) reported that egg laying varied from scattered few to clusters containing 118 per batch up to a maximum of 390 per moth

2 6 5 Feeding behaviour

Satheesan *et al* (1987) observed the caterpillars as nocturnal in feeding habit Mumappan *et al* (1989) reported that the larvae feed gregariously until third instar and then disperse From fourth instar onwards the larvae feed at night and hide under litter and debris on the ground during the day They observed that the larvae consumed terminal and axillary buds first and then remaining tender leaves

2 6 6 Defoliation efficiency

In Sri Lanka, where the insect has well established in the field, *C odorata* bushes have been killed due to constant defoliation by the insect (Kanagaratnam, 1976) Further, its preference for feeding on the growing tips reduced flowering during the months of November and December Muniappan and Marutani (1988c) reported that defoliation caused most shoots of the plant to dry up and continuous

defoliation of new sprouts from basal clumps resulted in total death of *Chromolaena* bushes Mumappan *et al* (1989) studied the defoliation efficiency of the insect and recorded that 50 larvae can cause 78 9 to 82 4 per cent reduction of leaf area in a plant of one metre height Seibert (1989) reported that 100 per cent of the weed at the release site was defoliated soon after the establishment of the arctiid in Guam Seibert (1989) observed that the shoot tips were eaten and virtually all buds de stroyed and the plant had no resource other than to produce new shoots from the root crown which were defoliated as they emerged from the ground Thus feedmg by continuous generations of the insect exhausted plant resources He reported that 18 months after establishment in Guam, the insect had defoliated approximately 25,000 hectares of the weed Joy *et al* (1993) reported the sporadic appearance and defolia tion of 12 hectares of the weed in Kerala during 1988

2 6 7 Food consumption and utilization

Muniappan *et al* (1988b) conducted laboratory studies at Coimbatore to find out the Consumption Index (CI), Growth Rate (GR), Efficiency of Conversion of Ingested Food (ECI), Approximate Digestibility (AD) and Efficiency of Conversion of Digested food (ECD) on wet weight basis The results showed that the Consumption Index was higher at later instars than the earlier instars There was variation in GR, ECI and ECD between different instars The decline of AD in later instars of lepidopterous insects was already reported earlier by Waldbauer (1968)

2 6 8 Host reaction of *C odorata* due to feeding by *P pseudoinsulata*

2 6 8 1 Yellowing of leaves

Both damaged and undamaged leaves of the plant turn yellow, after

attack by the arctiid This was caused by physiological changes induced in the plants due to chemical stimuli produced by insects (Marutani and Muniappan, 1988) According to them, chlorophyll content was much lower in insect infested leaves than leaves from artificially defoliated plants and the artificial defoliation could not induce the same type of yellowing in leaves under natural infestation Muniappan and Marutani (1988c) observed that feeding of the insect caused the leaves of *Chromolaena* to change from green to yellow Mc Fadyen *et al* (1991) studied the changes in leaves due to feeding of insect and found that the amount of chlorophyll and rate of photosynthesis were reduced in yellow plants It was also reported that a distinct change occurred in small sub-units of ribulose-1, 5-bisphosphate carboxylase in yellow leaves Besides, a preliminary experiment of flavonoid analysis suggested additional compounds present in insect induced yellow leaves Joy *et al* (1993) also reported yellowing of the infested weeds in Kerala

2 6 8 2 Toughening of tissues

When caterpillars of *P pseudoinsulata* fed on leaves they became tough (Marutani and Muniappan, 1988)

2 6 8 3 Presence of elements

Green and insect induced yellow leaves were analysed for N, P, Na, K, Ca, Mg, Zn, Cu, Fe, Mn and nitrate N The results showed that the amount of total N, P, Na, K, Ca, Mg, Zn and Cu did not differ between green and yellow leaves while Fe and Mn showed differences and the element Fe was higher in concentration in yellow leaves than in green leaves (Marutani and Mumappan, 1988) They also reported that the amount of nitrate nitrogen was much higher in yellow leaves than green leaves

2 6 8 4 Palatability

The caterpillars favoured green leaves, but when they were in third instar or older they consumed yellow leaves also (Marutani and Muniappan, 1988)

2 6 8 5 Drying of plant

Feeding of the insect caused most shoots of the plant to dry up and continuous defoliation of new sprouts from basal clumps resulted in total death of *Chromolaena* bushes (Muniappan and Marutani, 1988c)

2 6 9 Limitations for the establishment of *P pseudoinsulata*

The reasons for the low field population and non establishment of the insect are climatic factors, disease epidemics, parasitization and predation (Joy *et al* 1993)

The influence of the different factors in limiting the spread of the bio-agent are reviewed in the following sub-sections

2 6 9 1 Natural enemies of the insect

There are several parasitoids, predators and pathogens as limiting factors for the establishment of the insect

2 6 9 1 a Parasitoids

Cruttwell (1969) observed that the eggs of *P pseudoinsulata* were heavi ly parasitized by a sceliomd - *Telenomus* sp and larvae by four species of tachinids

Calocarcelia aureocephala Thomp , *Lespesia pollinosa* Thomp , *Pygophorinae peruvianae* Towns and *Uromacquarria trinitatus* Thomp Napompeth *et al* (1988) reported heavy parasitization by tachinids in field collected larvae One parasitoid recovered from the insect in the field is *Exorista civiloides* (Bak) whose parasitism of late instar larvae grew from 1 10 per cent shortly after the establishment of the insect, to a high of 30 per cent, eight generations later The reason for the low field population and non establishment in many locations of Kerala may be the parasitiza tion by tachinids and phorids (Joy *et al* , 1993)

2 6 9 1 b Predators

Sankaran and Sugathan (1974) reported that the failure of *P pseudoinsulata* to establish was suspected to be due to detrimental activities of more than one species of predatory ants Simmonds (1976) stated that predatory ants were the primary cause for non establishment of the insect in India Singh (1980) attributed the failure of establishment to activity by predaceous ants in the field Esguerra *et al* (1991) observed the ants interfering with laboratory cultures by preying on eggs and larvae of the insect The predators such as ground lizards, spiders, birds and red or black ants preyed heavily on adults, larvae and eggs of the insect (Esguerra *et al* , 1991) The cause for non establishment of the insect in Natal, South Africa is probably because of heavy predation by ants (Kluge, 1991) Seibert (1989) reported that predators are important in restricting *Pareuchaetes* populations Birds of various species were found frequenting the area and were suspected to be predaceous, however the gut contents of the birds showed no remnants of caterpillars (Joy *et al* , 1993)

2 6 9 1 c Pathogens

Singh (1980) has attributed the failure of establishment of *P pseudoinsu lata* to a granulosis virus in the laboratory cultures In Trinidad NPV was found infecting the insect (Chacko and Narasimham, 1988) Joy *et al* (1993) observed that in Kerala the dead field collected caterpillars were found infected with bacteria and recorded epidemics due to NPV as being common both in the laboratory and the field

2 6 9 2 Egg viability

Napompeth *et al* (1988) observed that almost all eggs laid failed to hatch in spite of successful mating observed in the egg laying cages Napompeth and Winotai (1988) reported that laboratory rearing of the insect was observed to deteri orate after every four generations, when all the eggs failed to hatch While rearing the insect in the laboratory, a few eggs from the majority of egg masses laid on the leaves of *Chromolaena* and the screen of the rearing cages failed to hatch for unknown reasons Torres *et al* (1991) reported that one of the major problems encountered in the use of *Pareuchaetes* is the hatchability of its eggs Most of the egg masses laid by the moth were infertile resulting in complete loss of a laboratory stock According to him, there was a wide range of infertility of F_2 egg massess among the different mating combinations tried In F_2 adults the range was 18 per cent to 100 per cent and in F_3 adults from 25 per cent to 100 per cent They con cluded that infertility of eggs of pests bred on the Siam weed appears to be a result of several interrelated factors such as lack of mating, influence of light and inbreed ing Inbalance in the proportion of males and females resulting from inbreeding is

perhaps the most important factor that leads to absence of mating (Torres *et al* , 1991)

2 6 9 3 Inhibition of insect development induced by the host plant

Marutani and Muniappan (1988) reported that by feeding on yellow leaves, the insect development was inhibited while growth rate was much greater when they were fed on green leaves They also stated that there was no regular pattern of insect movement on the plants corresponding to day-night rhythms

2 6 9 4 Climatic changes

Cock and Holloway (1982), Cock (1984) and Esguerra *et al* (1991) speculated that the insect failed to establish in West Africa and India because these areas have a very pronounced dry season Climatic factors could be a factor for the low field population of the insect in Vellanikkara (Thrissur, Kerala) and non-establishment of it in many locations in Kerala (Joy *et al* , 1993)

Materials and Methods

MATERIALS AND METHODS

The Sri Lankan strain of *P pseudoinsulata* caterpillars received from the Commonwealth Institute of Biological Control, Bangalore during July, 1982 formed the nucleus culture for the present studies which were carried out during 1990 1993 The insect was continuously reared under laboratory conditions and released in fields in the rubber plantations of the Kerala Agricultural University in its main Campus Vellanikkara, where heavy weed populations were available

For the experiments, fresh eggs collected from the infested rubber estate plants in the main campus were used for labaoratory rearing in rearing cages of size 60 cm x 60 cm x 90 cm made out of wooden frame to which plain glass sheets were fitted on two sides and metallic netting at the back The bottom of the cage was with wooden plank of 1 cm thickness and top with metallic netting In the front side, a door consisting of wooden frame and metallic netting was provided in such a manner that on closure it fitted tightly without leaving any gaps

The well cleaned, sun dried cages were swabbed with cotton pads soaked with mercuric chloride 0 1 per cent and left for a period of five hours before use Fresh tender shoots of *Chromolaena* were cut and bouquets of these were inserted into conical flasks containing water The bouquets were tightly held in the conical flask using cotton pad packing in the neck around the stems to block the passage of the larvae from the foliage into water White paper was kept at the bottom of the cage for easy removal of excreta that falls from the bouquet Every day larvae were transferred into new sterile rearing cages having fresh bouquets, with the help of

fine hair brushes Pupation occurred within the bouquets or on the floor of the cage and these were collected and kept individually in paper strips spread at the bottom of the cage Such placement of pupae helped in easy emergence of the adults The emerging adults were collected and transferred to oviposition cages of size 30 cm x 30 cm x 45 cm made of wooden frame to which glass panels were fitted on the two sides and metallic wire netting at the back side The bottom was provided with wooden plank of 1 cm thickness and top with plain glass Front door was of metal lic netting fitted on wooden frame (Plate 1) Sterile cotton pre-soaked in honey and water solution (1 1) was placed in petri dishes to provide food for the moths Bouquets of *Chromolaena* shoots were kept in the cages for resting and egg laying

3 1 Biological studies

Adult pairs were kept separately in plastic containers of size 12 cm height and 8 cm diameter for egg laying (Plate 2) *Chromolaena* leaves were kept in these containers and sterile cotton dipped in honey and water solution (1 1) was provided as food for adults Adults started egg laying from the next day The date of egg laying was noted on the container and the adults were then transferred to fresh containers Thus 30 batches of egg masses laid on different dates by adults of differ ent ages were collected

Eggs used for experimental purpose were rinsed in 0 2 per cent solution of sodium hypochlorite and then transferred into 10 per cent formaldehyde solution for one hour Finally the eggs were placed under gently running tap water for one hour, then air dried and held in sterile cages for hatching

Plate 2 Plastic containers used for individual rearing of larvae

The caterpillars emerging from these eggs were collected and placed singly on the leaves of *C odorata* with the cut end of the petiole wrapped up with wet cotton padding to prevent drying The insects were reared in plastic containers of size 12 cm height and 8 cm diameter in which fresh supply of food was provided The dates of casting away of exuviae were recorded for studying the duration of various instars Pre-pupal, pupal periods and adult life span were also recorded during the course of rearing Small cotton balls dipped in honey solution (50 per cent) were hung from the covering cloth using metal pins This served as food for the adults The experiment was laid out in Completely Randomised Design and conducted at room temperature during the months of June-July, 1992

3 2 Morphology and morphometrics

Studies on morphology and morphometrics were made by rearing the insect in plastic containers as already described

3 2 1 Larva

Length and maximum width of larvae were measured using dividers and a 10 cm scale For this twenty five larvae were first anaesthetised with chloroform for facilitating the measurements The characters were studied for the I stage larvae on the day of emergence itself, for II stage on the third day, for III stage on the fifth day for IV stage on the eighth day, V on eleventh day, VI on fourteenth day and for the VII stage on the nineteenth day The weight of the anaesthetised larvae were also recorded using an electronic balance

3 2 2 Pre pupa

Length, breadth and weight of pre pupa were recorded as above

3 2 3 Pupa

Pupae were examined for male and female characters Length, breadth and weight were also measured

3 2 4 Adult

For adults, male and female characaters were studied separately Observations were made on total body length, maximum body width, wing span and antennal length For studying wing venation, the specimens were boiled in five per cent KOH for five minutes for removing the scales from the wings When specimens became transparent, they were transferred to acetic acid acid fuchsin solution to neutralise the alkalinity They were then transferred to carbol xylol (1 3) for dehydration The dehydrated specimens were mounted in Canada balsam for examination

3 3 Studies on fecundity and egg hatchability

In order to determine the most suitable concentrations of adult food and adjuvants, an experiment was conducted in the laboratory The following twelve treatments consisting of different food materials were given in this experiment

1 Honey alone

2 Vitamin E alone

3 Honey and water solution (1 1)

4 Honey and water solution (1 1) fortified with 0 2 per cent vitamin E

5 Honey and water solution (1 1) fortified with 0 4 per cent vitamin E

6 Honey and water solution (1 1) fortified with 0 6 per cent vitamin E

7 Honey and water solution (1 1) fortified with 0 1 per cent sodium chloride

8 Honey and water solution (1 1) fortified with 0 2 per cent sodium chloride

9 Honey and water solution (1 1) fortified with 0 3 per cent sodium chloride

10 Honey and water solution (1 1) fortified with 0 1 per cent sucrose

11 Honey and water solution (1 1) fortified with 0 2 per cent sucrose

12 Honey and water solution (1 1) fortified with 0 3 per cent sucrose

Based on hatchability of eggs, the fortifications consisting of 0 4 per cent vitamin E, 0 1 per cent sodium chloride and 0 2 per cent sucrose in 1 1 honey solu tion were selected for further experimentation The selected treatments were then evaluated at two temperature humidity regimes and three adult sex ratios, with 20 replications in each treatments, in growth chambers

a) Fortifications

1 Honey and water (1 1)

2 Honey and water (1 1) fortified with 0 4 per cent vitamin E

3 Honey and water (1 1) fortified with 0 1 per cent sodium chloride

4 Honey and water (1 1) fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E

5 Sucrose solution (0 2 per cent) fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E

6 Water

b) Temperature humidity regimes

25°C and 75 per cent RH

30°C and 60 per cent RH

c) Sex ratios

1 1 Female male

1 2 Female male

2 1 Female male

Adults on the day of eclosion were collected and kept at the above three sex ratios in plastic containers of size 12 cm height and 8 cm diameter Different food combinations were prepared and supplied in sterile cotton balls, hung from the cloth cover by pinning Tender shoots of *Chromolaena* with wet cotton wraps at the cut ends were placed in the containers and were offered for resting and egg laying After the death of the female moth, total number of eggs laid per female were counted to assess the fecundity The eggs were allowed to hatch at the same tempera ture, humidity regimes itself and the hatchability recorded

3 4 Feeding habits of larval instars

The relative preference of the larvae to tender and mature leaves was assessed by conducting feeding trials

3 4 1 Characterisation of leaves

For demarcating tender and mature leaves, thin longitudinal sections of the leaves were taken and the intercellular spaces of the collenchymatous tissue were

measured It was found that in the first to third pair of leaves from the top, the intercellular space was negligible These leaves were light green in colour and deli cate in texture From fourth to eighth pair, the intercellular space ranged from 0 66 μ to 3 30 μ in thickness These leaves were deep green in colour Leaves from the eighth pair downwards showed yellowing, a sign of senescence and in this case, the thickness recorded was above 3 50 μ

3 4 2 Feeding experiments

Since the early stages of larvae were too delicate and small which pro-duce inconspicous feeding marks on the lamina, five larvae were placed together on a leaf for studying their feeding habits From the sixth day onwards, the larvae were placed individually The experiment was carried out in plastic containers with 20 replications, under laboratory conditions

The weight and area of leaves offered as well as the weight of larvae were found out at an interval of 24 hours Every time the cut end of the leaf petioles were covered with wet cotton to prevent drying The left over food was carefully taken out and weighed The area of the left over leaf was also recorded Then new leaves were introduced Natural weight loss from the leaves were determined after 24 hours, using separate lots of leaves The area of the leaf was measured by using a Leaf Area Meter and weights determined by an electronic balance

3 4 2 1 Larval food consumption and growth

The indices of larval food consumption and growth were calculated as follows according to Waldbauer (1968) and Scriber (1977)

3 4 2 1 a Consumption Index (C I)

$$C I = F/TA$$

where F Fresh weight of food eaten by the larvae

T Duration of feeding period

A Mean fresh weight of insect during feeding period

3 4 2 1 b Relative Growth Rate (R G R)

$$R G R = G/TA$$

where G Fresh weight gain of the larvae during the feeding period

T Duration of feeding period

A Mean fresh weight of insect during feeding period

Feeding trials were also conducted for the larvae by feedmg them with partially yellow leaves and fully yellow leaves

3 5 Metabolic changes in plants due to feeding of the insect

Field cages of 3 m height and 1 m diameter, with open bottom were made with mosquito net fixed on to metallic frame (Plate 3) Umform sized *C odoraia* plants were selected from the field and the cages were placed over it by pressing the metal frame at the bottom into the soil to prevent the escape of the larvae from the cage Third instar larvae were released on the plant in varying numbers of 0 (control), 4, 6, 8, 10 and 12 with each treatment replicated thrice Leaf samples were drawn before the release of the larvae and on 4th, 6th, 8th, 10th, 12th and 15th days after release for analysis of total nitrogen, soluble nitrogen and chlorophyll ('a', b' and total) contents

3 5 1 Total nitrogen

Nitrogen content of the leaves was analysed by the microkjeldhal method (Piper, 1966) The results were presented as per cent nitrogen in the leaves on dry weight basis

3 5 2 Soluble nitrogen

This was determined as per the method of Bremner and Keeney (1965) and presented as percentage of nitrate nitrogen on w/w basis

3 5 3 Chlorophyll

Chlorophyll 'a' and 'b' and total chlorophyll were estimated following the procedure of Mahadevan and Sridhar (1986) Chlorophyll content was estimated as per cent of the fresh weight of leaves

3 6 Collection and identification of natural enemies

3 6 1 Parasitoids

Egg masses and caterpillars collected from field were kept in plastic containers for emergence of parasitoids The emerging larval parasitoids were reared in the laboratory and their parasitisation on fresh hosts studied To obtain egg para sitoids, egg masses from laboratory reared adults were suspended on *Chromolaena* plants to remain at 200 cm above ground level for two days and collected thereafter They were then kept in cages for emergence of egg parasitoids

3 6 2 Predators

In areas frequented by birds, they were killed using an air gun and the gut dissected out to determine the detritus and remnants in the viscera Ants being another group of predators and which were preying on insects were collected and identified

3 6 3 Pathogens

Dead larvae found hanging from or remaining on the leaves were col lected from field and laboratory for examination For general diagnostic work, wet mount and smear of the specimens were prepared The specimens/mounts/ smears were then observed under a microscope to confirm the preliminary diagnosis and the pathogens involved were identified

3 6 3 1 Preparation of wet mount

The wet mount was made by dissecting out a small portion of tissue or taking up a drop of body fluid with a capillary tube, placing this in a drop of water on a slide and covering it with a coverslip This was then examined microscopically for the presence of pathogens Ringing the coverslip with 'Vaspar' was also done for further belated examinations Vaspar was prepared by melting together equal amounts of vaseline and paraffin

3 6 3 2 Smear preparation

Body fluid was smeared on a clean slide and allowed to air dry Tissue smears were prepared by dissecting out a small amount of the selected tissue which is squashed on the slide and spread as thinly as possible It was then allowed to air dry and fixed by gentle heating

3 6 3 3 NPV isolation

Polyhedral inclusion bodies were detected under the light microscope They were differentiated from fat droplets by adding a drop of saturated aqueous Sudan III at the edge of the coverslip and allowing it to flow through Polyhedra did not stain while fat droplets stained red The presence of polyhedral bodies were also identified by placing a small drop of I N NaOH at the edge of the coverslip and allowing it to flow through and then observing the material under high dry (400 x) magnification As the alkali flowed through, the polyhedra swelled up and then got dissolved

3 6 3 4 Isolation of bacteria

When bacteriosis was evident in the smear, the bacteria present in the haemocoel and tissues were isolated for identification In order to eliminate surface contaminants, the insect was sterilized externally with 0 1 per cent $HgCl_2$ for 1 2 minutes It was then washed with three changes of sterile distilled water and placed in a sterile dissecting dish The specimen was then dissected with sterile scissors by cutting the integument along the longitudinal dorsal line All instruments used for dissection were also sterilized, first by autoclaving and then by dipping in 70 per cent ethanol and by flaming off the alcohol Blood and body fluid were sampled with a sterile capillary tube diluted in 2 ml sterile water and plated on potato dextrose agar (PDA) by streak plate method Tissues were sampled by cutting out a small piece which is placed in 2 ml sterile water and triturated with a sterile glass rod The suspension was then streaked on PDA plates The plates were incubated at room temperature and then examined The bacterial colonies were then brought into pure

culture This was done by taking a small sample from a well isolated colony with a sterile loop, and suspending it in 2 ml sterile water The suspension was then streaked on a fresh agar plate, incubated and examined the next day for purity

3 6 3 5 Testing micro-organisms for pathogenicity

Suspension of virus and bacteria were prepared by triturating diseased hosts in sterile water and filtering through cheese cloth to remove larger particles Suspensions were further cleaned by gross filtration through ordinary laboratory filter paper (Whatman No 1) The filtrate was then checked microscopically for the pathogen This was taken for testing pathogenicity of the micro-organism by oral inoculation *Chromolaena* leaves were dipped in the suspension and supplied to the larvae for feeding For adults, the suspension was mixed with honey and cotton balls dipped in the mixture were kept in adult rearing cages for feeding

3 7 Statistical analysis

Statistical analyses of the data generated in the experiment was done by employing the methods described by Snedecor and Cochran (1967)

RESULTS

4 1 Biological studies

4 1 1 Egg laying

Oviposition trials involving different lots of adults of *P pseudoinsulata*, showed that eggs were laid singly in clusters mostly on undersurfaces of leaves

4 1 2 Duration of life stages

Mean incubation period for the eggs at ambient temperature 28 4°C and 68 per cent RH was recorded as 5 5 days There were seven larval instars with a duration of 2 15, 2 20, 1 95, 3 30, 2 95, 4 40 and 4 35 days for first, second, third, fourth, fifth, sixth and seventh instars, respectively The total larval duration was 21 30 days Pre pupal period was 1 5 days the mean pupal period 10 15 days (n = 25) Adult life span occupied 8 3 days (Table 1)

4 2 Morphology and morphometrics

4 2 1 Eggs

Creamy white in colour and domeshaped Chorion transluscent, smooth and shiny (Plate 4) Mean weight of 25 eggs was 0 005 g The eggs measured 0 969 mm in diameter with a range of 0 918 1 003 mm (n = 25)

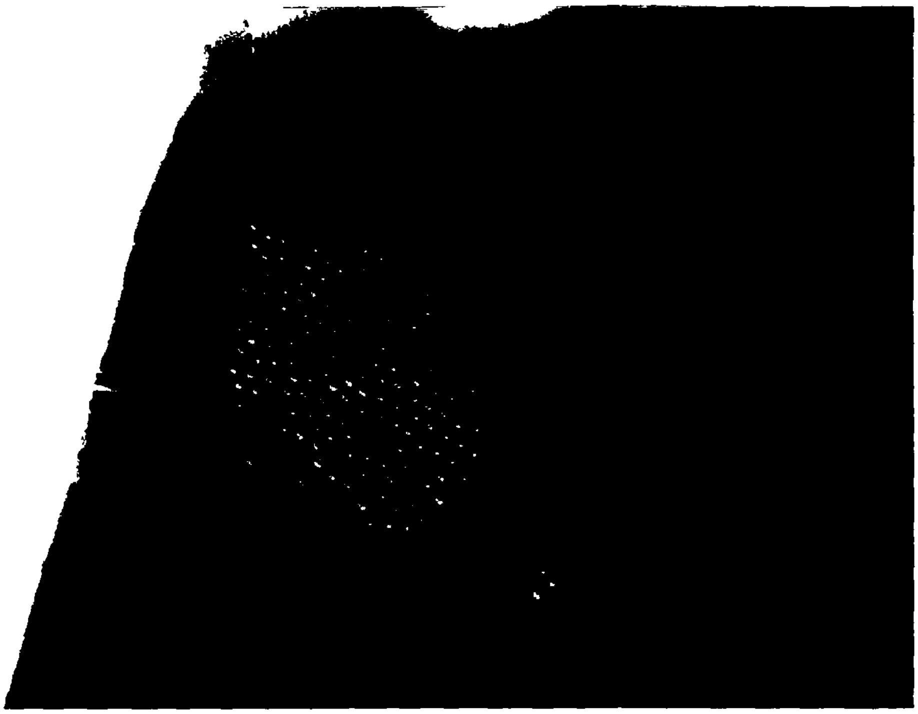
Eggs turned black at the dorsal aspect on the day of hatching due to the darkening of the head capsule of the larvae (Plate 5)

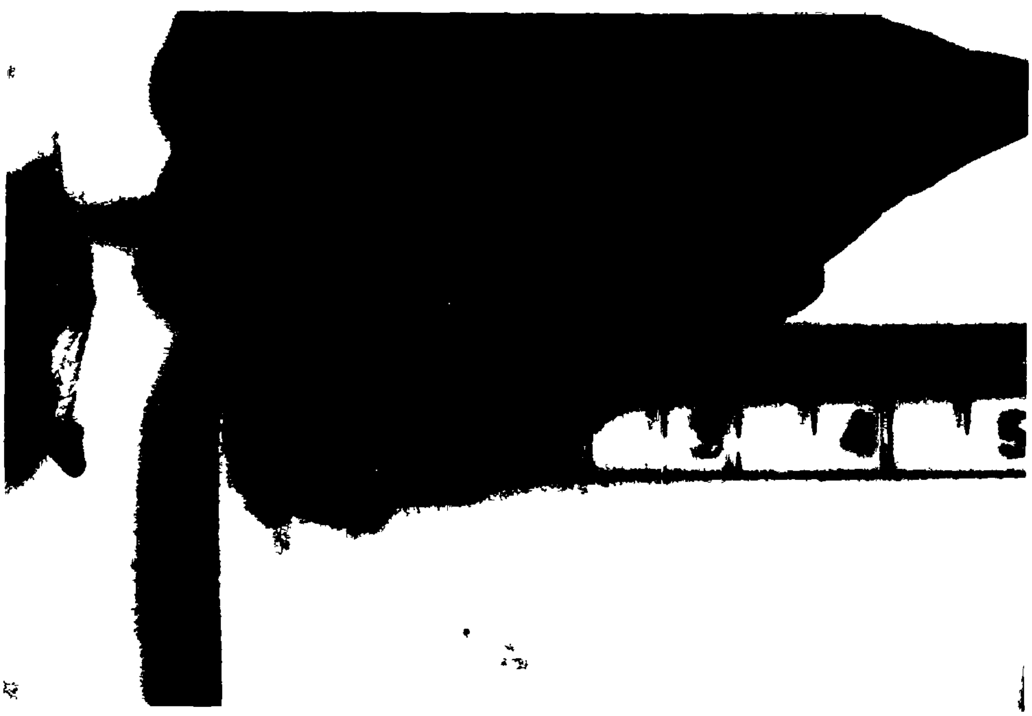
Table 1 Duration of life stages (days) of *P pseudoinsulata*

Stage	Mean	Range	Standard Error
Egg	5 50	5 6	0 087
I instar	2 15	2 3	0 082
II instar	2 20	2 3	0 092
III instar	1 95	1-3	0 088
IV instar	3 30	2 4	0 193
V instar	2 95	3-6	0 266
VI instar	4 40	3-5	0 407
VII instar	4 35	3 5	0 646
Larva	21 30	16-29	0 327
Pre pupa	1 50	1-2	0 096
Pupa	10 15	8 13	0 221
Adult	8 30	8 10	0 128
Total	46 75	38 59	

Plate 4 Egg mass of *P pseudoinsulata*

Plate 5 Eggs on the day of hatching





4 2 2 Larva

There were seven larval instars The larval features are as follows (Table 2 and 3)

4 2 3 I Instar

Head black and body greyish-white with orange tinge Black pm head sized dots on dorsal and lateral sides of all the three thoracic segments On the abdommal segments, semi lunar black spots are present on the dorsum and laterally circular black spots are present Dull black proleg pairs present Body clothed m minute hairs Mean body length 3 900 $\pm$ 0 191 mm and maximum breadth 0 825 $\pm$ 0 055 mm (n = 25) (Plate 6)

4 2 4 II Instar

Head capsule greyish-white with a prominent black spot Thoracic segments greyish with a large black spot on the first dorsally and elongated irregular black specks on the second Third thoracic segment with orange-red irregular marking First abdominal segment black with orange coloured spots on the dorsal aspect The rest of the abdominal segments dull black on the dorsal side and orange coloured laterally Seventh abdominal segment black Black dots on the dorsum and white nearby straight lines on lateral side all along abdomen Black and white tufts of hairs all over the body Body length 5 450 $\pm$ 0 114 mm and breadth 1 00 mm (n = 25) (Plate 7)

Plate 6 I instar larva of *P pseudoinsulata*

Plate 7 II instar larva of *P pseudoinsulata*

4 2 5 III Instar

Morphological features similar to the II instar, but body colouration more prominent Tufts of hairs on the body longer and denser Body length 6 50 ± 0 115 mm and breadth 1 00 mm (n = 25) (Plate 8)

4 2 6 IV Instar

Head black First thoracic segment dull-black with an inverted triangular black marking on the dorsal aspect Second segment black, but the third one orange red with white specks First, seventh and ninth abdominal segments blackish, other segments being black with prominent orange irregular specks Tufts of hairs visible all over the dorsal and lateral sides Body length of 8 350 ± 0 182 mm and maximum body width 1 156 ± 0 082 mm (n = 25)

4 2 7 V Instar

Head and thoracic segments black, but white and orange markings present on the second and third segments First, seventh and ninth abdominal segments fully black, and all others black tinged with prominent orange and white shaded specks White and black tufts of hairs present all over the body Body length 11 750 ± 0 347 mm and breadth 2 00 mm (n = 25)

4 2 8 VI Instar

Similar to fourth and fifth instars Mean length 18 850 ± 0 563 mm and breadth 2 80 ± 0 117 mm (n = 25)

Plate 8 III instar larva of *P pseudoinsulata*

4 2 9 VII Instar

Mean length 22 100 ± 0 403 mm and breadth 3 550 ± 0 135 mm (n = 25) Morphological characters similar to VI instar (Plate 9)

4 2 10 Pre-pupa

Head reduced Body black with reddish markings Length and breadth 17 90 ± 0 250 mm and 4 850 ± 0 082 mm (n = 25) (Plate 10)

4 2 11 Pupa

Pupae obtect, dark brown with a length of 14 250 ± 0 250 mm and breadth 5 00 ± 0 162 mm (n = 25) (Plate 11)

4 2 12 Adult

Adults medium sized, creamy yellow Wing span for females 39 50 mm and 35 50 mm for males Antennae bipectinate Maximum body length 13 55 ± 0 02 mm for males and 15 650 ± 0 023 mm for females (n = 25) Breadth 4 100 ± 0 069 mm and 5 500 ± 0 115 mm for males and females, respectively (n = 25) (Plate 12)

4 3 Male and female characters

Males and females were similar in all the stages except in size and weight (Table 4)

4 3 1 Adult

Males smaller in size with slender abdomen Genital opening narrow in males Mean dry weight 0 025 g for males and 0 043 g for females Body length

Table 2 Total length of different life stages (mm) of *P pseudoinsulata*

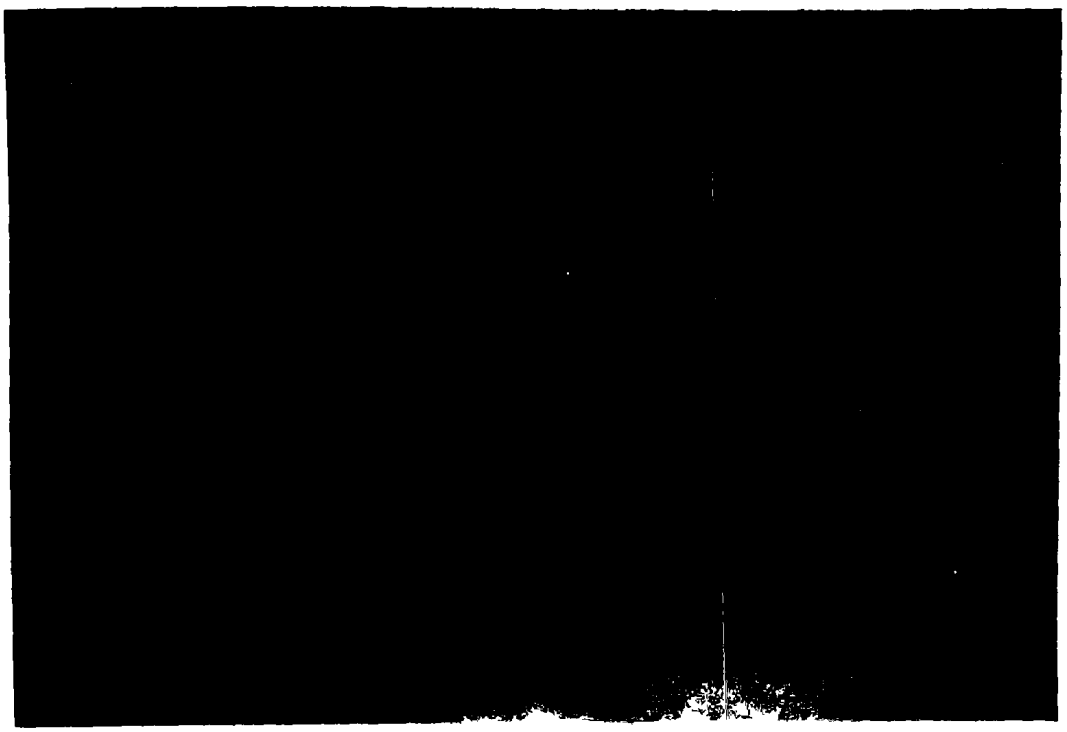
Stage	Mean	Range	Standard Error
I instar	3 900	3-5	0 191
II instar	5 450	5 6	0 114
III instar	6 500	6 7	0 115
IV instar	8 350	7 9	0 182
V instar	11 750	10-14	0 347
VI instar	18 850	14-25	0 563
VII instar	22 100	19-25	0 403
Pre pupa	17 900	16-19	0 250
Pupa	14 250	12-16	0 250
Adult Male	13 550	12 16	0 020
Adult Female	15 650	13-18	0 023

Table 3 Maximum breadth of different life stages (mm) of *P pseudoinsulata*

Larva	Mean	Range	Standard Error
I instar	0 825	0 5-1	0 055
II instar	1 000	1 00	
III instar	1 000	1 00	
IV instar	1 156	1 2	0 082
V instar	2 000	2 00	
VI instar	2 800	2-4	0 117
VII instar	3 550	3-5	0 135
Pre-pupa	4 850	4-5	0 082
Pupa	5 000	4-6	0 162
Adult Male	4 100	4 5	0 069
Adult Female	5 500	5-6	0 115

Plate 9 Fully grown larva of *P pseudoinsulata*

Plate 10 Pre pupa of *P pseudoinsulata*



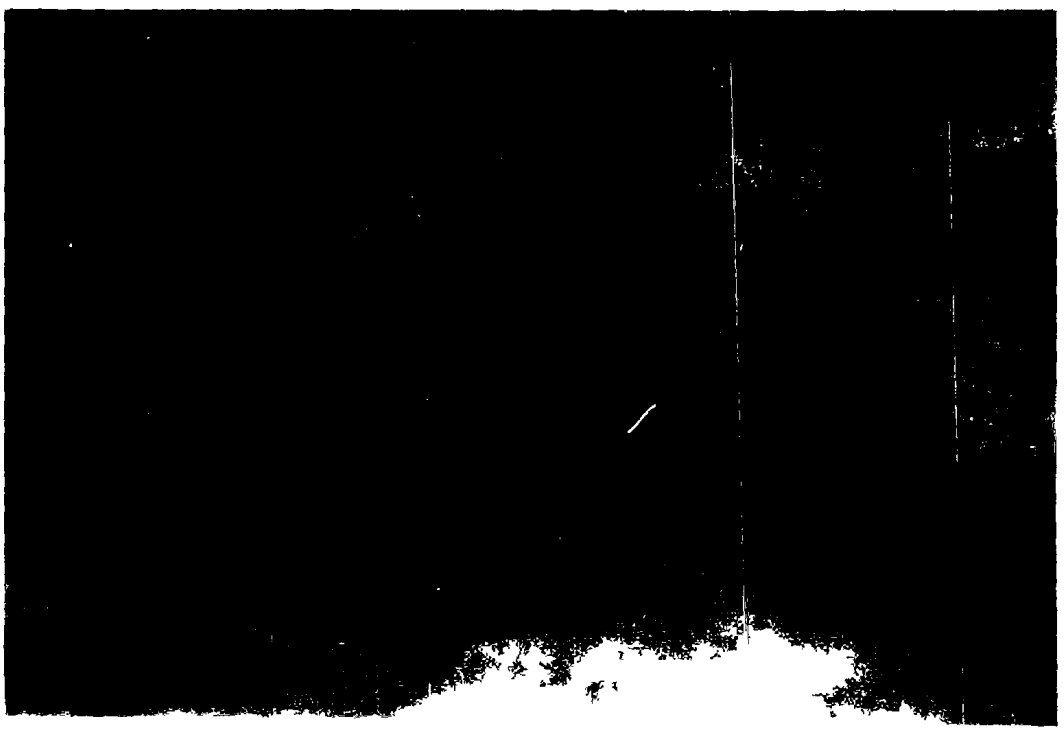
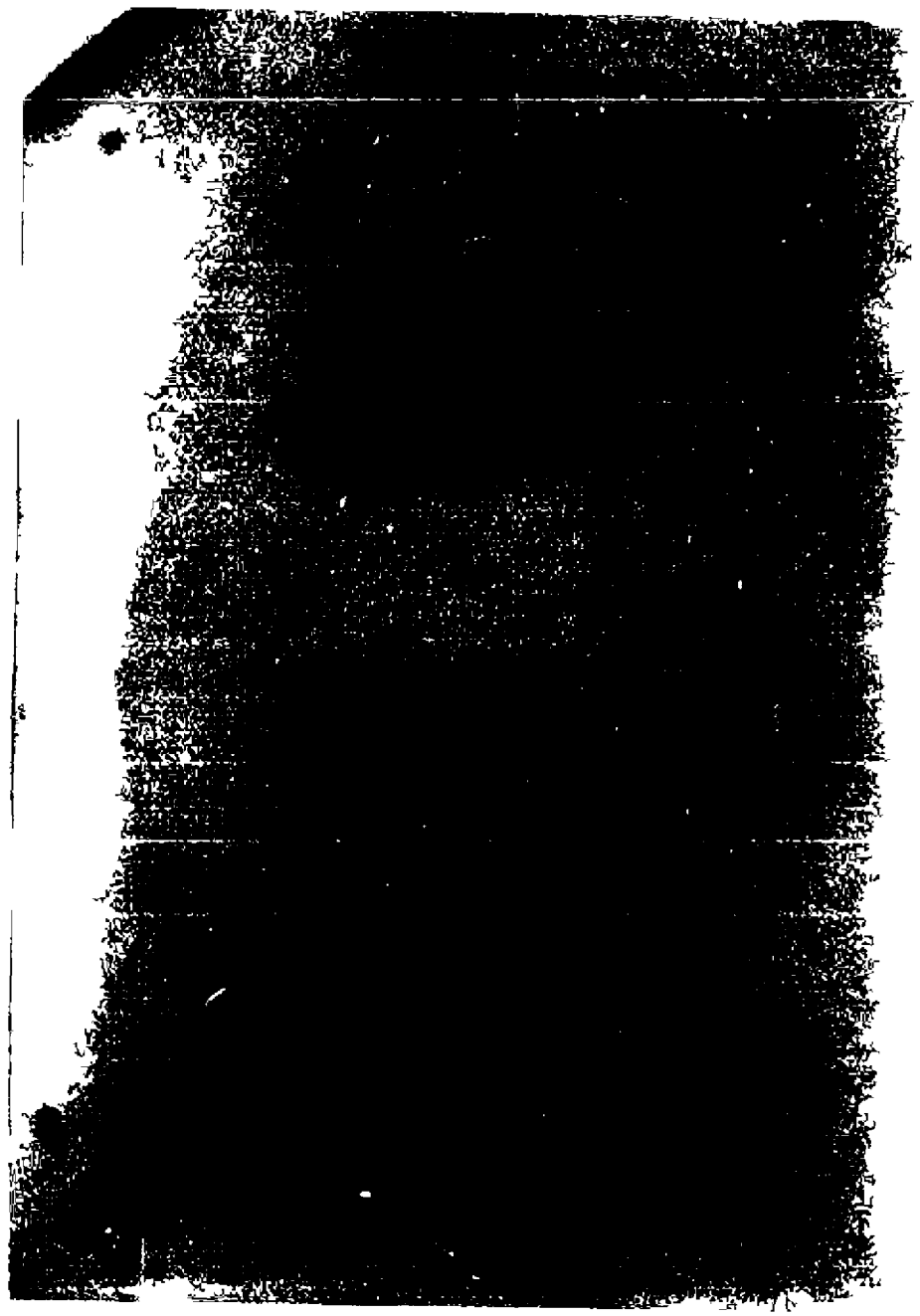


Plate 11 Pupa of *P pseudoinsulata*

Plate 12 Adult moths of *P pseudoinsulata*



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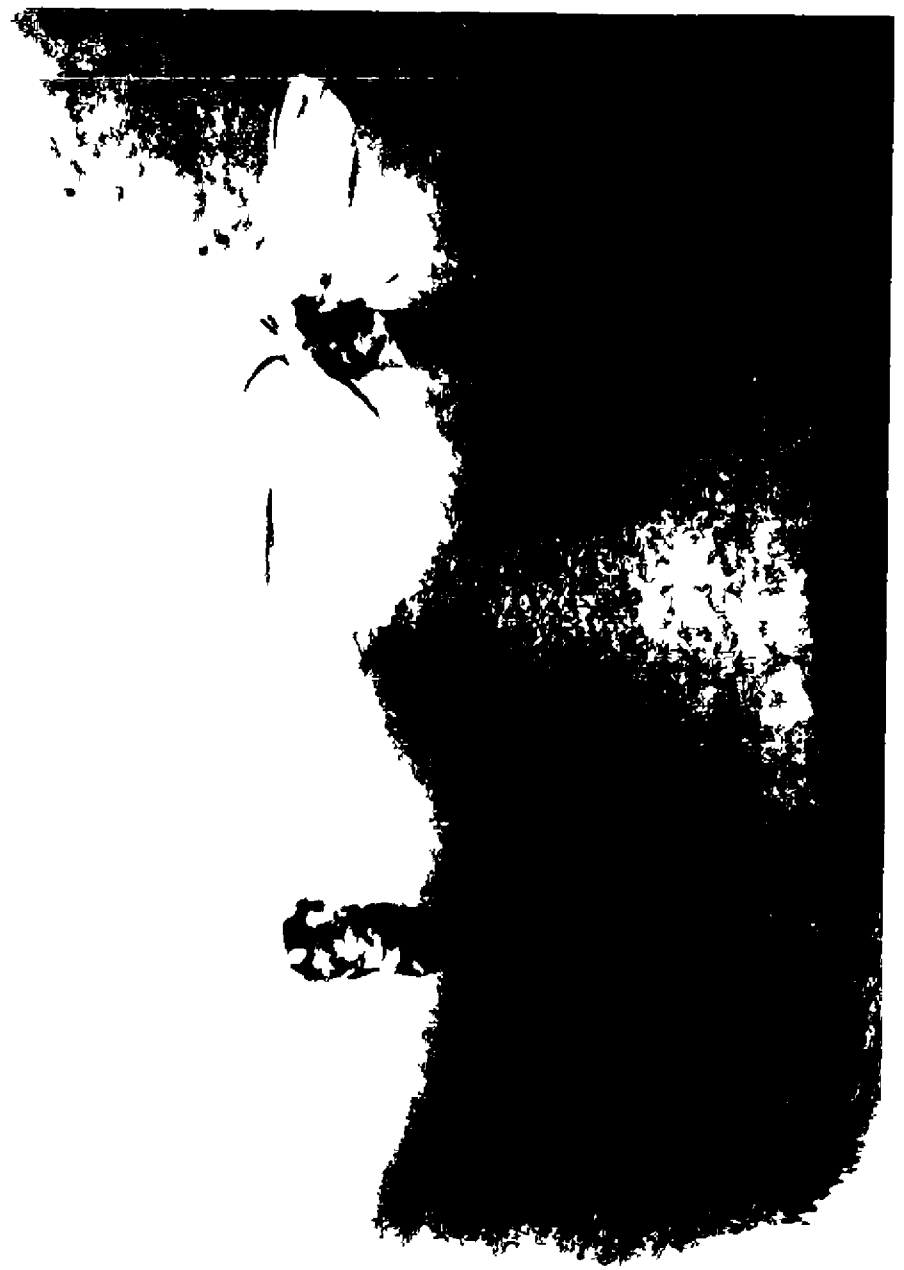


and breadth of males and females 13 65 mm x 4 10 mm and 15 60 mm x 5 50 mm (n = 25) The wing span was found to be significantly lower in males (35 50 mm) than in females (39 50 mm) Average antennal lengths of males and females were 8 mm and 8 3 mm, respectively Adult life span 7 05 days and 7 40 days for males and females, respectively, there being no significant variability among the sexes

4 3 2 Larva

Maximum larval weight recorded for males was 0 238 g and that for females was 0 306 g Mean larval period was 21 70 days for females and 19 45 days for males Maximum length and breadth were 24 550 mm x 4 150 mm for males and 24 950 mm x 5 050 mm for females The male and female larvae differed sig nificantly in respect of length, breadth, weight and period

4 3 3 Pupa

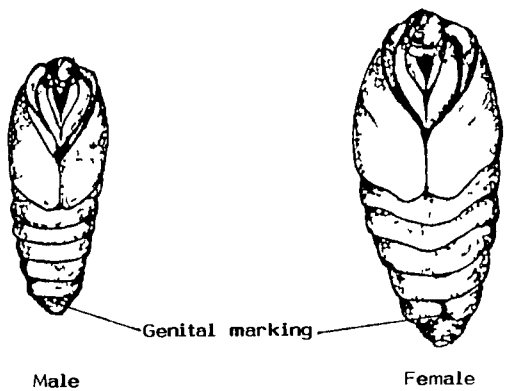
Mean pupal weight recorded for male was 0 129 g and 0 174 g for female In the case of female pupa the genital marking was very prominent near the anterior margin of eighth abdominal segment, while in the male it was located on the ninth abdominal segment (Fig. 1) Maximum pupal length and breadth recorded for male pupa was 13 650 mm x 4 700 mm and for female pupa 15 00 mm x 5 15 mm and was significantly different Pupal period was 10 30 days for both males and females

Table 4 Comparison of male and female characters of *P pseudoinsulata*

Characters	Male	Female
Adult weight (g)	0 025	0 043*
Adult length (mm)	13 650	15 600*
Adult breadth (mm)	4 100	5 500*
Wing span (mm)	35 500	39 500*
Antennal length (mm)	8 000	8 300
Adult period (days)	7 050	7 400
Maximum larval weight (g)	0 238	0 306*
Larval period (days)	19 450	21 700*
Maximum larval length (mm)	24 550	24 950*
Maximum larval breadth (mm)	4 150	5 050*
Pupal weight (g)	0 129	0 174*
Pupal period (days)	10 300	10 300
Pupal length (mm)	13 650	15 000*
Pupal breadth (mm)	4 700	5 150*

* Significant at 5% level

Fig.1. Male and female pupae of *P. pseudoinsulata*



4 4 Feeding habit of larvae

The feeding preference of the larvae to tender, mature, partially yellow and yellow leaves were assessed by conducting feeding trials

4 4 1 Feeding on tender leaf

When tender leaves were consumed, the larval stage got extended from seven to eight instars The data on weight of various instars, leaf weight consumed and the consumption indices are furnished in Table 5

4 4 1 1 Larval weight

The maximum larval weight was for the eighth instar (0 211 g), this being significantly higher than all other instars First instar recorded least weight (0 0005 g) but this was on par with II and III instars in respect of larval weight

4 4 1 2 Leaf consumption

It was maximum for VIII instar (0 352 g) followed by VII and VI instars in that order, these being significantly different The leaf consumption of I, II, III and IV instars were statistically on par

4 4 1 3 Consumption index

Consumption index was maximum for the I instar (26 00) followed by II III and IV instars in that order The seventh instar recorded minimum consump tion index (0 370) and it was on par with the indices of V, VI and VIII instars

Table 5 Larval weight, tender leaf consumption and consumption index at various instars

Instar	Weight of larvae (g)	Weight of leaf consumed (g)	Consumption Index
I	0 0005 e	0 024 e	26 000 a
II	0 002 e	0 020 e	5 350 b
III	0 004 e	0 014 e	2 155 c
IV	0 010 de	0 063 e	2 143 c
V	0 041 d	0 108 cd	0 484 d
VI	0 112 c	0 155 c	0 452 d
VII	0 163 b	0 238 b	0 370 d
VIII	0 211 a	0 352 a	0 793 d

Means followed by the same letter are not significantly different at 5% level

4 4 1 4 Weight increase of larval instars

The increment in weight was maximum during V to VI instar (0 070 g) followed by the VI to VII instars (0 060 g) The rates of increment in these two growth stages being on par Least weight increase was from II to III (0 002 g) and I to II (0 002 g) instars (Table 6)

4 4 1 5 Relative growth rate

Relative growth rate was maximum from I instar to II instar (1 650) and least from VII to VIII instars (0 084) (Table 6)

4 4 2 Feeding on mature leaf

When mature leaves were fed to the larvae, there were seven larval in star› The data on weight of different instars, weight of leaf consumed and consump tion index values are presented in Table 7

4 4 2 1 Larval weight

Maximum weight recorded was for VII instar (0 230 g) followed by VI V and IV instars which were all significantly different The least weight was record ed was for I instar (0 0005 g)

4 4 2 2 Leaf consumption

The fifth instar consumed maximum quantity of leaf (0 469 g), followed by the VII instar (0 419 g) but their consumption levels were not statistically differ ent

Table 6 Larval weight increase and relative growth rate at various instars when consumed tender leaves

Instars	Weight increase (g)	Relative growth rate
I to II	0 002 d	1 650 a
II to III	0 002 d	0 313 d
III to IV	0 006 cd	1 002 b
IV to V	0 031 bc	1 075 b
V to VI	0 070 a	0 549 c
VI to VII	0 060 a	0 208 de
VII to VIII	0 047 ab	0 084 e

Means followed by the same letter are not significantly different at 5% level

4 4 2 3 Consumption Index

Second instar showed maximum consumption index (5 000) followed by I (2 965) and V instars (2 297) The least consumption index was recorded for the VI instar (0 526) and this was on par with the VII instar (0 801)

4 4 2 4 Weight increase of larval instars

Weight increase of larval instars was also assessed when they were fed mature leaves Significantly higher weight increase was recorded from the VI to VII (0 096 g) and the V to VI (0 095 g) instars which were all on par Least weight increase was from I to II stage (0 001 g) which was on par with II to III, III to IV and IV to V stages (Table 8)

4 4 2 5 Relative growth rate

It was maximum from IV to V stage (1 581) and minimum from VI to VII stage (0 214) (Table 8)

4 4 3 Feeding on semi yellow leaf

When semi yellow leaves were offered to the I and II instar larvae,they did not feed these leaves and died due to starvation Therefore, the I and II instar larvae were reared on green leaf and from III instar onwards put on semi yellow leaves There were seven larval instars when semi yellow leaves were consumed Observations recorded on weight of larva, weight of leaves consumed and consump tion index are given in Table 9

Table 7 Larval weight, mature leaf consumption and consumption index at various instars

Instar	Weight of larvae (g)	Weight of leaf consumed (g)	Consumption Index
I	0 0005 e	0 004 c	2 965 b
II	0 002 e	0 020 c	5 000 a
III	0 004 e	0 013 c	1 533 d
IV	0 013 d	0 037 c	1 683 cd
V	0 039 c	0 469 a	2 297 bc
VI	0 134 b	0 274 b	0 526 d
VII	0 230 a	0 419 a	0 801 d

Means followed by the same letter are not significantly different at 5% level

Table 8 Larval weight increase and relative growth rate of different instars when consumed mature leaves

Instars	Weight increase of larvae (g)	Relative growth rate
I to II	0 001 b	0 881 abc
II to III	0 002 b	0 558 cd
III to IV	0 008 b	0 964 ab
IV to V	0 026 b	1 581 a
V VI	0 095 a	0 645 bc
VI VII	0 096 a	0 214 d

Means followed by the same letter are not significantly different at 5% level

4 4 3 1 Larval weight

Larval weight was maximum for the VII instar (0 193 g) which was significantly higher than for the VI (0 142 g) and V (0 034 g) instars

4 4 3 2 Leaf weight consumed

Seventh instar consumed maximum leaves (0 243 g) followed by the VI instar (0 199 g) which were significantly different Least feeding was recorded by the III instar (0 023 g)

4 4 3 3 Consumption index

Significantly higher consumption index were recorded for the IV (3 784) and III instars (3 143) than V, VI and VII instars

4 4 3 4 Weight increase of larvae

Maximum weight increase was recorded for the V to VI instar (0 109 g) which was significantly higher than all other stages and least for III to IV instar (0 006 g) Details are given in Table 10

4 4 3 5 Relative growth rate

Maximum relative growth rate recorded was for the IV to V instar (1 297) which was significantly higher than all other stages (Table 10)

4 4 4 Consumption of yellow leaves

When yellow leaves were fed, the I and II instar larvae did not consume the leaves and died due to starvation Therefore, yellow leaves were given from the

Table 9 Larval weight, weight of semi yellow leaf consumption and consumption index

Instar	Weight of larvae (g)	Weight of leaf consumed by larvae (g)	Consumption Index
III	0 004 e	0 023 d	3 143 a
IV	0 010 d	0 067 c	3 784 a
V	0 034 c	0 083 c	0 646 b
VI	0 142 b	0 199 b	0 471 b
VII	0 193 a	0 243 a	0 564 b

Means followed by the same letter are not significantly different at 5% level

Table 10 Larval weight increase and relative growth rate when consumed semi yellow leaves

Instars	Weight increase of larvae (g)	Relative growth rate (g)
III to IV	0 006 d	0 763 b
IV to V	0 024 a	1 297 a
V to VI	0 109 a	0 842 b
VI to VII	0 051 b	0 124 c

Means followed by the same letter are not significantly different at 5% level

III instar onwards and observations were recorded from this stage onwards (Table 11 and 12) When yellow leaves were consumed, there were eight larval instars

4 4 4 1 Larval weight

Maximum larval weight was recorded for VIII instar (0 206 g) which was significantly higher than all other instars

4 4 4 2 Leaf weight consumed

The VIII instar consumed maximum leaf weight (0 323 g) followed by VII and VI instars which were all significantly different

4 4 4 3 Consumption index

The index was maximum for the III instar (2 500) which was significant ly higher than all other instars and it was least for VIII instar (0 447)

4 4 4 4 Weight increase of larvae

Maximum weight increase was recorded from the VII to VIII instar (0 105 g) and it was significantly higher than all other instars and least for III to IV instar (0 012 g)

4 4 4 5 Relative growth rate

It recorded a high value for IV to V (1 527) followed by III to IV (1 209) which were on par Least relative growth rate was from VI to VII instar (0 176)

Table 11 Larval weight, weight of yellow leaf consumption and consumption index

Instar	Weight of larvae (g)	Weight of leaves consumed (g)	Consumption Index
III	0 004 f	0 010 d	2 500 a
IV	0 016 e	0 072 c	2 498 a
V	0 049 d	0 087 c	0 671 b
VI	0 109 c	0 131 c	0 641 b
VII	0 141 b	0 267 b	1 046 ab
VIII	0 206 a	0 323 a	0 447 b

Means followed by the same letter are not significantly different at 5% level

Table 12 Larval weight increase and relative growth rate when yellow leaves consumed

Instars	Weight increase of larvae (g)	Relative gorwth rate
III to IV	0 012 c	1 209 a
IV to V	0 031 c	1 527 a
V to VI	0 060 b	0 474 b
VI to VII	0 031 bc	0 176 b
VII to VIII	0 105 a	0 397 b

Means followed by the same letter are not significantly different at 5% level

4 4 5 Larval weight on consumption of tender, mature, semi-yellow and yellow leaves

When weight of III, IV, V, VI and VII larval instars were compared by feeding the larvae with tender, mature, semi yellow and fully yellow leaves, it was found that VII instar had maximum larval weight (0 230 g) on consuming mature leaves, followed by the VII instar (0 193 g) which consumed semi yellow leaves and these were significantly different (Table 13)

4 4 6 Consumption index of different larval instars when fed tender, mature, semi yellow and yellow leaves

Consumption index was maximum for IV instar (3 784) followed by III instar (3 143) when supplied semi yellow leaves The least consumption index was for the VII instar (0 370) which fed tender leaves (Table 14)

4 4 7 Relative larval growth rate when fed tender, mature, semi yellow and yellow leaves

It was maximum when the larva changed from the IV to V instar (1 581) on mature leaf diet and minimum when the larva changed from the VI to VII instar (0 124) on a semi yellow leaf diet The results are presented in Table 15

4 4 8 Effect on larval, pupal and adult periods and weights when fed tender mature, semi-yellow and yellow leaves

The larvae were fed with different types of leaves and recorded the difference in duration and weights of various stages of the insect It was found that when tender leaves were consumed there was a significantly higher larval (22 45 days) pupal (10 40 days) and adult (7 90 days) periods than the periods recorded when the other kinds of leaves were consumed (Table 16 and Fig 2)

Table 13 Mean larval weight (g) when consumed tender, mature, semi yellow and yellow leaves

Instar	Larval weight (g)
Tender	
III	0 004 j
IV	0 010 hij
V	0 041 fg
VI	0 112 e
VII	0 163 c
Mature	
III	0 004 j
IV	0 013 hi
V	0 039 g
VI	0 134 d
VII	0 230 a
Semi yellow	
III	0 004 j
IV	0 010 hij
V	0 034 g
VI	0 142 d
VII	0 193 b
Yellow	
III	0 004 j
IV	0 002 i
V	0 049 f
VI	0 109 e
VII	0 141 d

Means followed by the same letter are not significantly different at 5% level

Table 14 Consumption Index at various instars when supplied tender, mature, semi yellow and yellow leaves

Instar	Consumption Index
Tender	
III	2 155 cd
IV	2 143 cd
V	0 484 g
VI	0 452 g
VII	0 370 g
Mature	
III	1 533 def
IV	1 683 de
V	2 297 bc
VI	0 526 fg
VII	0 801 efg
Semi yellow	
III	3 143 abc
IV	3 784 a
V	0 646 fg
VI	0 471 g
VII	0 564 fg
Yellow	
III	2 50 bcd
IV	2 498 bcd
V	0 671 fg
VI	0 641 fg
VII	1 046 efg

Means followed by the same letter are not significantly different at 5% level

Table 15 Relative growth rate of various instars when supplied tender, mature, semi yellow and yellow leaves

Instars	Reglative growth rate
Tender	
III IV	1 002 cdef
IV V	1 075 bcde
V - VI	0 549 fghi
VI VII	0 208 hi
Mature	
III IV	0 964 cdefg
IV V	1 581 a
V VI	0 645 efgh
VI VII	0 214 hi
Semi yellow	
III IV	0 763 defg
IV V	1 297 abc
V VI	0 842 cdefg
VI VII	0 124 i
Yellow	
III IV	1 209 abcd
IV - V	1 527 ab
V VI	0 474 ghi
VI VII	0 176 hi

Means followed by the same letter are not significantly different at 5% level

Maximum weight was recorded when the mature leaves were offered This recorded a larval weight of 0 277 g, pupal weight of 0 158 g and adult weight of 0 059 g Minimum pupal and adult weights were recorded when the insect consumed yellow leaves, eventhough the larval weight was on par with the larvae fed on other three types of leaves (Table 17 and Fig 3)

4 4 9 Leaf weight and leaf area consumption

Larvae were fed with four types of leaves, namely, tender, mature, semi-yellow and yellow leaves and the leaf area and leaf weight consumed were recorded from the third instar onwards Larvae consumed a maximum leaf weight of 1 212 g of mature leaves and a minimum of 0 615 g of semi-yellow leaves from the third instar onwards (Fig 4)

In the case of leaf area consumed, maximum was for tender leaves (260 80 cm^2), which was significantly higher than that of the other three types Minimum leaf area consumption was for semi yellow leaf (126 30 cm^2) followed by fully yellow leaf (147 70 cm^2) these two treatments being on par (Table 18 and Fig 5)

In general, a positive significant correlation exists between leaf area and leaf weight consumed (r value = 0 650)

4 5 Studies on fecundity and egg hatchability

An experiment with 12 treatments was conducted in the laboratory to record the fecundity of adults and percentage egg hatchability Results are given in

Table 16 Effect on duration of different stages of the insect

Type of leaf consumed	Larval period (days)	Pupal period (days)	Adult period (days)
Tender	22 45 a	10 40 a	7 900 a
Mature	19 68 c	9 500 b	6 300 b
Semi yellow	19 09 c	9 200 b	6 300 b
Yellow	20 68 b	9 800 ab	5 600 b

Means followed by the same letter are not significantly different at 5% level

Table 17 Effect on weight of different stages of the insect

Type of leaf consumed	Larval weight (g)	Pupal weight (g)	Adult weight (g)
Tender	0 260 a	0 141 a	0 052 a
Mature	0 277 a	0 158 a	0 059 a
Semi yellow	0 229 a	0 139 a	0 036 b
Yellow	0 238 a	0 095 b	0 029 b

Means followed by the same letter are not significantly different at 5% level

Fig. 2. Effect on duration of different stages of the insect when fed with four types of leaves

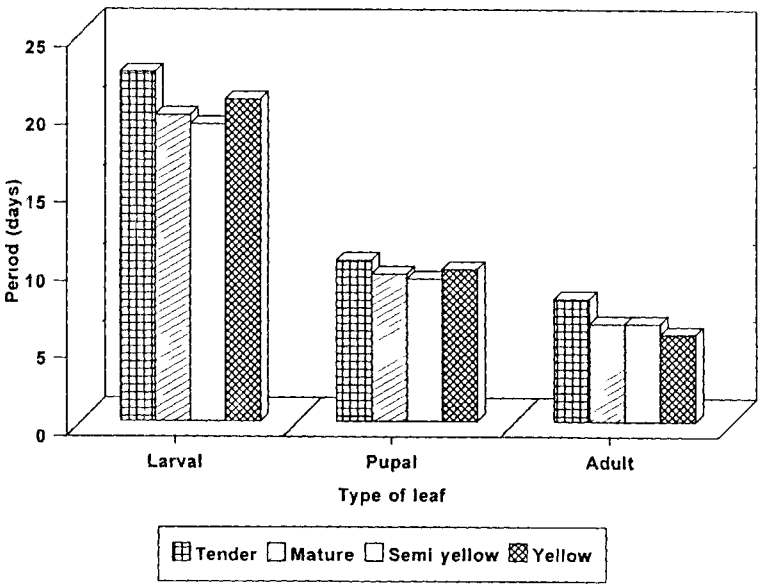


Fig.3. Effect on weight of different stages of the insect when fed with four types of leaves

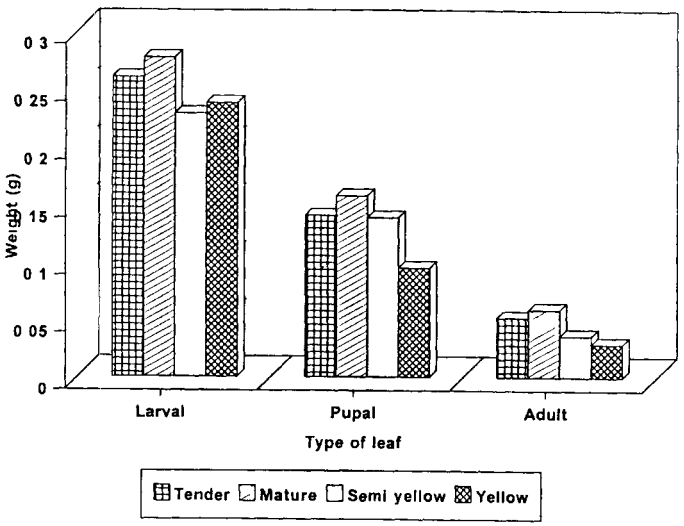


Table 18 Pattern of consumption of leaves by *P pseudoinsulata*

Type of leaf consumed	Leaf weight consumption (g)	Leaf area consumption (cm^2)
Tender	0 881 c	260 8 a
Mature	1 212 a	209 6 b
Semi yellow	0 615 d	126 3 c
Yellow	1 029 b	147 7 c

Means followed by the same letter are not significantly different at 5% level

Fig.4. Pattern of leaf weight consumption by *P. pseudoinsulata*

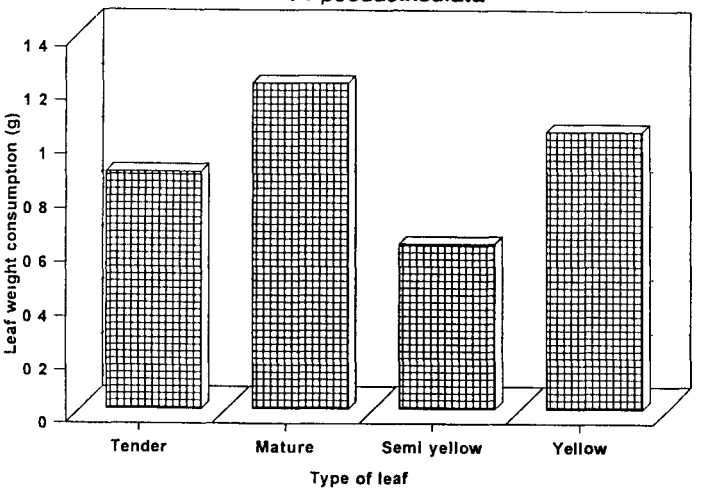


Fig.5. Pattern of leaf area consumption by *P. pseudoinsulata*

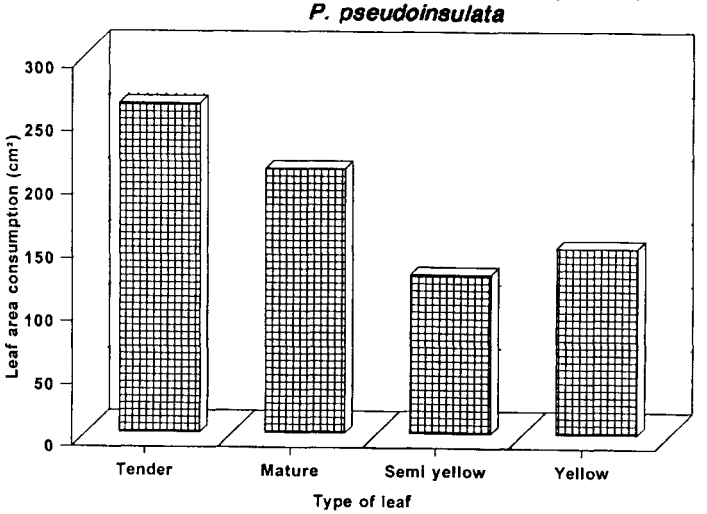


Table 19 Based on the results, a factorial experiment with three sex ratios, two temperature humidity regimes and six food combinations were conducted to study their effect on adult fecundity and egg hatchability The results of this experiment are explained below

4 5 1 Effect of sex ratio

The fecundity was maximum (214 70) at a 1 1 sex ratio, followed by 1 2 ratio (205 80) these being on par Significantly lower egg output was observed in 2 1 ratio (163 20)

Regarding viability, it was highest for 1 1 ratio (61 98 per cent) At the same time the percentage hatchability of eggs laid by females under confinement with males at 1 2 ratio was 58 19, the corresponding viability under 2 1 sex ratio being 51 40 per cent These two sex ratios were on par (Table 20) The adult fe cundity and percentage hatchability are graphically represented in Fig 6

4 5 2 Effect of temperature humidity regimes

The fecundity of adults was 216 27 eggs at 25°C and 75 per cent RH and 163 71 eggs at 30°C and 60 per cent RH, the outputs being significantly different Similarly significantly higher hatching percentage was observed at 25°C and 75 per cent RH (69 14) than at 30°C and 60 per cent RH (44 34) (Table 21 and Fig 7)

4 5 3 Effect of food combinations

Out of the six combinations evaluated honey + water (1 1) fortfied with 0 1 per cent sodium chloride gave maximum egg output (282 80) per female fol lowed by honey + water (1 1) with 0 1 per cent sodium chloride and 0 4 per cent

Table 19 Fecundity and egg viability as influenced by adult nutrition

Treatments	Eggs laid	Eggs hatched	Percentage hatchability
1 Honey alone	179 33	108 00	60 224
2 Vitamin E alone	172 00	81 00	47 093
3 Water alone	176 38	98 02	55 573
4 Honey + water (1 1) + 0 2% vitamin E	221 80	145 94	65 762
5 Honey + water (1 1) + 0 4% vitamin E	331 16	261 00	78 950
6 Honey + water (1 1) + 0 6% vitamin E	164 00	98 60	60 120
7 Honey + water (1 1) + 0 1% sodium chloride	257 0	213 00	82 879
8 Honey + water (1 1) + 0 2% sodium chloride	153 00	112 00	73 203
9 Honey + water (1 1) + 0 3% sodium chloride	253 00	179 00	70 751
10 Honey + water (1 1) + 0 1% sucrose	207 00	153 00	73 000
11 Honey + water (1 1) + 0 2% sucrose	300 75	222 60	74 200
12 Honey + water (1 1) + 0 4% sucrose	154 66	102 00	65 951

Table 20 Effect of sex ratio on fecundity and egg hatchability

Sex ratio	Eggs laid/female	Percentage hatchability
1 1	214 70 a	61 98 a
1 2	205 80 a	58 19 ab
2 1	163 20 b	51 40 b

Means followed by same letter are not significantly different at 5% level

Table 21 Effect of temperature-humidity regimes on fecundity and egghatchability

Temperature-humidity regimes	Eggs laid/female	Percentage hatchability
25°C, 75% RH	216 27 a	69 14 a
30°C, 60% RH	163 71 b	44 34 b

Means followed by the same letter are not significantly different at 5% level

Fig. 6. Effect of sex ratio on fecundity and egg hatchability

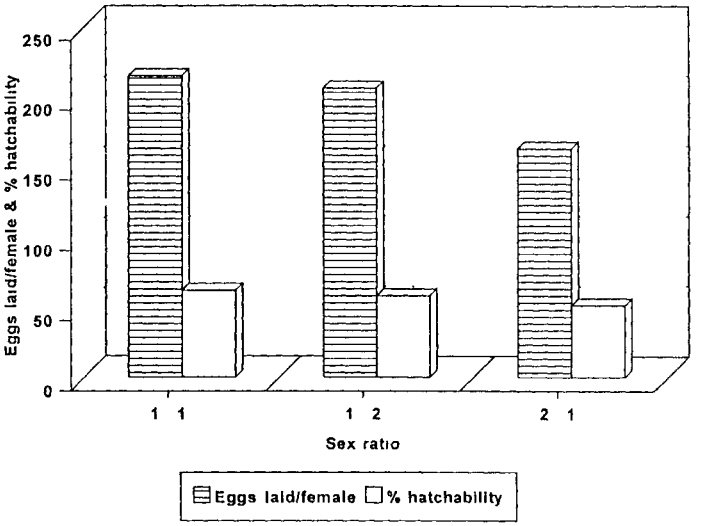
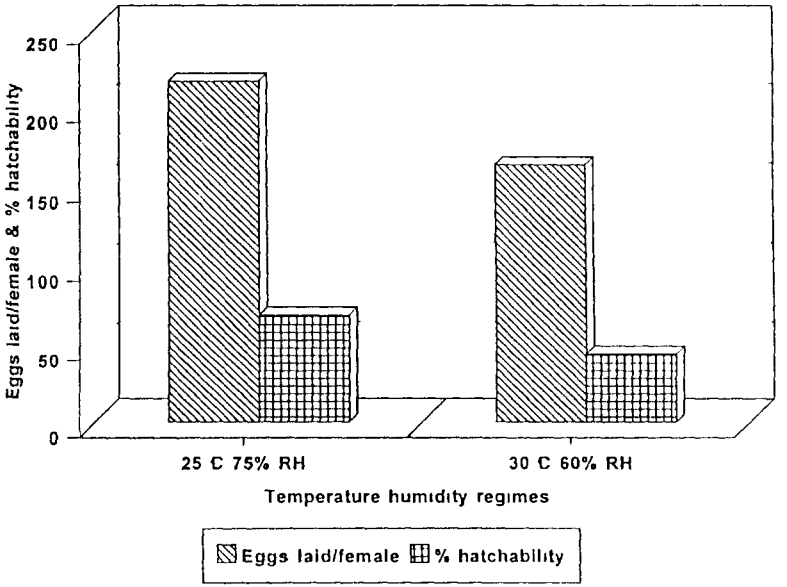


Fig.7.Effect of temperature - humidity regimes on fecundity and egg hatchability



vitamin E (264 00) When the adults were given water alone, the fecundity was 261 40 this being on par with the above two treatments

Regarding percentage hatchability, it was observed that the adults fed with water alone gave a significantly low hatchability (30 82) All other treatments were on par with a maximum of 65 54 per cent for honey + water (1 1) fortified with 0 1 per cent sodium chloride (Table 22 and Fig 8

4 5 4 Effect of interaction between sex ratio and temperature-humidity regimes

Interaction between sex ratio and temperature humidity regimes revealed that at a female-male ratio of 1 1 at temperature 25°C and 75 per cent RH, the adults laid maximum number of eggs (243 50) followed by 1 2 ratio under the same temperature and humidity levels (225 90) and these two treatment combinations were on par Significantly lower fecundity (149 50 eggs/female) was recorded for 2 1 sex ratio (30°C and 60 per cent RH)

The hatchability was significantly higher at all the three sex-ratios kept at temperature 25°C and 75 per cent RH with a maximum for 1 1 (73 31) At 30°C temperature and 60 per cent RH the three sex ratios recorded significantly lower hatchability with a least value for 2 1 ratio (32 71) (Table 23)

4 5 5 Interaction between sex-ratio and food combinations

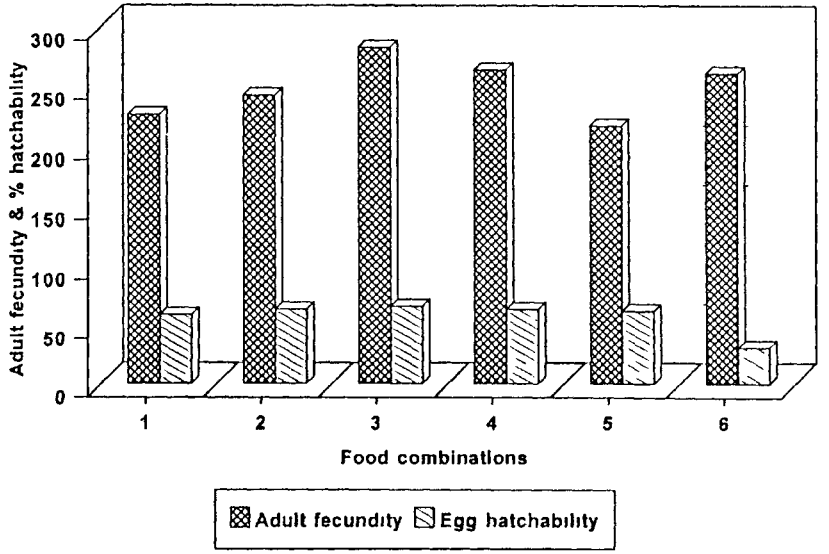
Interaction between sex-ratio and different food combinations showed that a high fecundity was realised for 1 1 sex ratio, when the adults were provided with honey + water (1 1) fortified with 0 1 per cent sodium chloride (255 30) Next in the order was for the 1 2 ratio with the same food (252 00) Honey + water (1 1)

Table 22 Effect of food combinations on fecundity and egg hatchability

Food combinations	Adult fecundity	Percentage hatchability
1 Honey + water (1 1)	226 10 cd	58 58 a
2 Honey + water (1 1) + 0 4% vitamin E	242 30 bc	63 17 a
3 Honey + water (1 1) + 0 1% sodium chloride	282 80 a	65 54 a
4 Honey + water (1 1) + 0 1% sodium chloride + 0 4% vitamin E	264 00 ab	63 21 a
5 Sucrose 0 2% + 0 1% sodium chloride + 0 4% vitamin E	217 30 d	61 82 a
6 Water	261 40 ab	30 82 b

Means followed by the same letter are not significantly different at 5% level

Fig. 8. Effect of food combinations on fecundity and egg hatchability



1-Honey+water (1 1), 2-Honey+water(1 1)+0 4% vitamin E, 3 Honey+water (1 1) + + 0 1% sodium chloride, 4-Honey+water (1 1) + 0 1% sodium chloride +0 4% vitamin E, 5-Sucrose 0 2% + 0 1% sodium chloride + 0 4% vitamin E, 6 - Water

Table 23 Effect of sex ratio at different temperature-humidity regimes on fecundity and egg hatchability

Sex ratio and temperature-humidity regimes	Adult fecundity	Percentage hatchability
Temperature-humidity regimes	25°C and 75% RH	
1 1	243 50 a	73 31 a
1 2	225 90 a	68 13 a
2 1	176 90 b	70 08 a
Temperature-humidity regimes	30°C and 60% RH	
1 1	185 90 b	50 64 b
1 2	185 70 b	48 25 b
2 1	149 50 c	32 71 c

Mean followed by the same letter are not significantly different at the 5% level

fortified with 0 4 per cent vitamin E was found equally good both 1 1 and 1 2 sex-ratios The least fecundity was realised when water alone and the sucrose 0 2 per cent fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E were supplied in these two sex ratios (Table 24) The sex-ratio 2 1 recorded lower fecund ity in all the food combinations

Percentage hatchability was higher in the sex ratio 1 1 when various food combinations were given, except in the case of water alone (37 14) At the 2 1 ratio also the hatchmg was least for when water alone was offered (24 32)

4 5 6 Interaction between food combination and temperature-humidity regimes

Significantly higher fecundity was recorded when the adults were reared at 25°C temperature and 75 per cent RH and fed honey + water (1 1) fortified with 0 1 per cent sodium chloride (336 90) But the same food combination gave a signif icantly lower fecundity when the temperature and relative humidity levels changed to 30°C and 60 per cent, respectively (242 10) In this case the least egg laying was 185 90 when the adults were given honey + water (1 1) fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E at 30°C and 60 per cent RH

Hatchability percentage of eggs was significantly higher for all the food combinations except water (38 12) at 25°C and 75 per cent RH But at 30°C and 60 per cent RH the hatchability was significantly low and it was least when water alone was given as food (23 51) (Table 25)

Table 24 Effect of sex ratio and food combination on fecundity and egg hatchability

Sex ratio and food combination	Fecundity	Egg hatchability
Sex ratio 1 2		
1 Honey + water (1 1)	203 70 bcd	64 28 abcde
2 Honey + water (1 1) + 0 4% vitamin E	238 60 ab	71 44 abcd
3 Honey + water (1 1) + 0 1% sodium chloride	255 30 a	80 19 a
4 Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	243 70 a	77 98 ab
5 Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	163 80 efgh	63 57 abcde
6 Water alone	183 10 cdefg	37 14 gh
Sex ratio 1 2		
1 Honey + water (1 1)	199 10 bcde	59 34 cde
2 Honey + water (1 1) + 0 4% vitamin E	218 00 abc	63 97 abcde
3 Honey + water (1 1) + 0 1% sodium chloride	252 00 a	75 48 abc
4 Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	117 40 defgh	56 40 def
5 Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	195 70 cdef	62 97 bcde
6 Water alone	198 80 cdef	31 00 h
Sex ratio 2 1		
1 Honey + water (1 1)	137 70 h	51 11 efg
2 Honey + water (1 1) + 0 4% vitamin E	173 40 defgh	54 10 ef
3 Honey + water (1 1) + 0 1% sodium chloride	159 40 fgh	40 95 fgh
4 Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	148 70 gh	55 95 def
5 Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	183 70 cdefg	58 91 cde
6 Water alone	176 40 defgh	24 32 h

Means followed by the same letter are not significantly different at 5% level

Table 25 Effect of temperature-humidity regimes and food combinations on fecundity and egg hatchability

Temperature -humidity regimes and food combinations	fecundity	Percentage hatchability
Temperature-humidity 25°C and 75% RH		
1 Honey + water (1 1)	235 70 def	75 39 a
2 Honey + water (1 1) + 0 4% vitamin E	265 30 bcd	78 75 a
3 Honey + water (1 1) + 0 1% sodium chloride	336 90 a	73 42 a
4 Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	248 70 cde	85 27 a
5 Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	273 80 bc	72 12 ab
6 Water alone	286 00 b	38 12 d
Temperature-humidity 30°C and 60% RH		
1 Honey + water (1 1)	216 40 fg	41 77 d
2 Honey + water (1 1) + 0 4% vitamin E	257 50 bcde	47 59 cd
3 Honey + water (1 1) + 0 1% sodium chloride	242 10 cdef	58 96 bc
4 Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	185 90 g	41 15 d
5 Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	210 80 fg	50 23 cd
6 Water alone	228 80 ef	23 51 f

Means followed by the same letter are not significantly different at 5% level

4 5 7 Effect on interaction between sex ratio, temperature humidity regimes and food combinations

When the three factor interactions were evaluated, adults at 1 1 ratio at 25°C temperature and 75 per cent RH gave significantly higher egg output when the adults were fed with honey + water (1 1) fortified with 0 4 per cent vitamin E, followed by honey + water (1 1) with 0 1 per cent sodium chloride, honey + water (1 1) with 0 1 per cent sodium chloride and 0 4 per cent vitamin E and water alone all these being on par Always a lower fecundity was recorded for 2 1 sex ratio at temperature 30°C and 60 per cent RH Lowest fecundity was observed in 1 1 ratio at 30°C temperature and 60 per cent RH when supplied with honey + water (1 1) fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E This showes that food combinations had no effect on fecundity, but had a decreasing trend at sex ratio 2 1 and when the temperature was raised 30°C and humidity to decreased 60 per cent (Table 26)

Regarding hatchability, the results showed that all the three sex ratios at 25 C temperature and 75 per cent RH recorded high egg hatchability for all the food combinations except water Least hatching occupied at 2 1 sex-ratio when water alone was given at temperature 30°C and RH 60 per cent (12 51) (Table 27)

4 6 Metabolic changes in plants due to feeding of the insect

4 6 1 Total nitrogen

When the total nitrogen content in the plant was assessed without consid ering days after release it was found that there was significant differences between the six treatments (Table 28) In control, the nitrogen was 2 608 per cent and the

Table 26 Effect of sex ratio, temperature humidity regimes and adult nutrition on fecundity

	Adult fecundity
Sex ratio 1 1 at 25°C and 75% RH	
Honey + water (1 1)	228 20 bcdefg
Honey + water (1 1) + 0 4% vitamin E	306 60 a
Honey + water (1 1) + 0 1% sodium chloride	269 90 abc
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	251 90 abcd
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	226 90 bcdefg
Water alone	279 30 ab
Sex ratio 1 1 at 30°C and 60% RH	
Honey + water (1 1)	179 20 ghijklmno
Honey + water (1 1) + 0 4% vitamin E	226 40 bcdefgh
Honey + water (1 1) + 0 1% sodium chloride	240 60 bcde
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	114 30 p
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	146 80 lmnop
Water alone	208 00 defghijk
Sex ratio 1 2 at 25°C and 75% RH	
Honey + water (1 1)	221 10 cdefghi
Honey + water (1 1) + 0 4% vitamin E	187 50 efghijklmn
Honey + water (1 1) + 0 1% sodium chloride	232 50 bcdefg
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	172 00 hijklmno
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	235 70 bcdef
Water alone	215 70 cdefghij
Sex ratio 1 2 at 30°C and 60% RH	
Honey + water (1 1)	177 10 ghijklmno
Honey + water (1 1) + 0 4% vitamin E	210 00 defghijk
Honey + water (1 1) + 0 1% sodium chloride	203 40 defghijk
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	170 80 hijklmno
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	155 80 klmnop
Water alone	195 40 efghijklm
Sex ratio 2 1 at 25°C and 75% RH	
Honey + water (1 1)	128 90 op
Honey + water (1 1) + 0 4% vitamin E	178 80 ghijklmno
Honey + water (1 1) + 0 1% sodium chloride	177 80 ghijklmno
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	161 10 jklmnop
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	202 50 defghijkl
Water alone	212 40 defghij
Sex ratio 2 1 at 30°C and 60% RH	
Honey + water (1 1)	146 50 mnop
Honey + water (1 1) + 0 4% vitamin E	168 00 ijklmnop
Honey + water (1 1) + 0 1% sodium chloride	141 10 mnop
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	137 30 nop
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	164 90 jklmnop
Water alone	140 40 mnop

Means followed by the same letter are not significantly different at 5% level

Table 27 Effect of sex ratio temperature humidity regimes and adult nutrition on egg hatchability

	Egg hatchability (%)
Sex ratio 1 1 at 25°C and 75% RH	
Honey + water (1 1)	76 38 abc
Honey + water (1 1) + 0 4% vitamin E	84 55 a
Honey + water (1 1) + 0 1% sodium chloride	87 54 a
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	76 96 abc
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	79 48 ab
Water alone	34 97 ijklmn
Sex ratio 1 1 at 30°C and 60% RH	
Honey + water (1 1)	52 18 defghijkl
Honey + water (1 1) + 0 4% vitamin E	58 33 bcdefghi
Honey + water (1 1) + 0 1% sodium chloride	62 74 bcdefgh
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	33 55 hijklmn
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	47 66 ghijkl
Water alone	39 31 ijklm
Sex ratio 1 2 at 25°C and 75% RH	
Honey + water (1 1)	74 93 abcde
Honey + water (1 1) + 0 4% vitamin E	76 71 abc
Honey + water (1 1) + 0 1% sodium chloride	80 44 ab
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	73 27 abcdef
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	75 99 abcd
Water alone	21 40 mn
Sex ratio 1 2 at 30°C and 60% RH	
Honey + water (1 1)	43 75 hijklm
Honey + water (1 1) + 0 4% vitamin E	51 23 efghijkl
Honey + water (1 1) + 0 1% sodium chloride	57 45 bcdefghij
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	55 34 cdefghijk
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	49 95 fghijkl
Water alone	48 38 ghijkl
Sex ratio 2 1 at 25°C and 75% RH	
Honey + water (1 1)	74 84 abcde
Honey + water (1 1) + 0 4% vitamin E	74 98 abcde
Honey + water (1 1) + 0 1% sodium chloride	80 72 ab
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	70 53 abcdefg
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	68 74 abcdefgh
Water alone	36 13 ijklmn
Sex ratio 2 1 at 30°C and 60% RH	
Honey + water (1 1)	29 38 lmn
Honey + water (1 1) + 0 4% vitamin E	33 22 klmn
Honey + water (1 1) + 0 1% sodium chloride	53 09 cdefghijkl
Honey + water (1 1) + 0 4% vitamin E + 0 1% sodium chloride	34 57 ijklmn
Sucrose 0 2% + 0 4% vitamin E + 0 1% sodium chloride	33 51 ijklmn
Water alone	12 51 n

Means followed by the same letter are not significantly differnt at 5% level

maximum nitrogen content was observed when four larvae were released (2 683 per cent) and minimum when 12 were released (2 47/per cent) and it was generally in a decreasing trend with the increasing the number of insects (Fig 9)

When total nitrogen content present in the plant was analysed by drawing the leaf samples before release, 4, 6, 8, 10, 12 and 15 days after release of the larvae without considering the number of larvae released significant differences were detected Before release, it was 2 755 per cent, and four days after release, it came down to 2 667 per cent, but again increased to 2 823 per cent on sixth day Thereafter a decreasing trend was observed for 8th, 10th, 12th and 15th days after release (Table 29 and Fig 10) It was maximum on sixth day when four larvae were released

4 6 2 Soluble nitrogen

The presence of soluble nitrogen in the plant was assessed after releasmg 0 4, 6, 8, 10 and 12 larvae on 4th, 6th, 8th, 10th, 12th and 15th days after release of the insect The results showed that with increase in the number of larvae and as the duration after release increased, there was an increasing trend in soluble nitrogen content But the increment did not show any statistical significance The least soluble nitrogen was in samples drawn from 'control' and just before release of the insect Maximum content of soluble nitrogen was on 15th day after release of the larvae (Tables 30, 31 and Fig 11,12)

4 6 3 Chlorophyll

Presence of chlorophyll 'a' in the plant was assessed after releasmg 0, 4, 6, 8, 10 and 12 numbers of larvae The results showed that there was a significant

Table 28 Changes m total nitrogen content due to the larval feeding

Sl No	Number of larvae released	Total nitrogen (%)
1	0	2 608 b
2	4	2 683 a
3	6	2 605 b
4	8	2 581 c
5	10	2 526 d
6	12	2 471 e

Means followed by the same letter are not significantly different at 5% level

Table 29 Changes in total nitrogen content after release of larvae

Sl No	Days after release	Total nitrogen (%)
1	0	2 755 b
2	4	2 667 c
3	6	2 823 a
4	8	2 509 d
5	10	2 398 e
6	12	2 324 f
7	15	2 202 g

Means followed by the same letter are not significantly different at 5% level

Fig 9. Changes in total nitrogen content due to feeding of different number of larvae

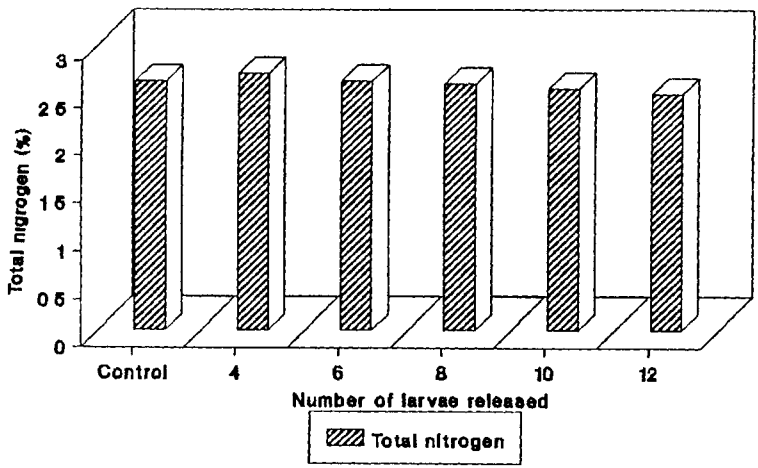


Fig.10. Changes in total nitrogen content on various days after release of larvae

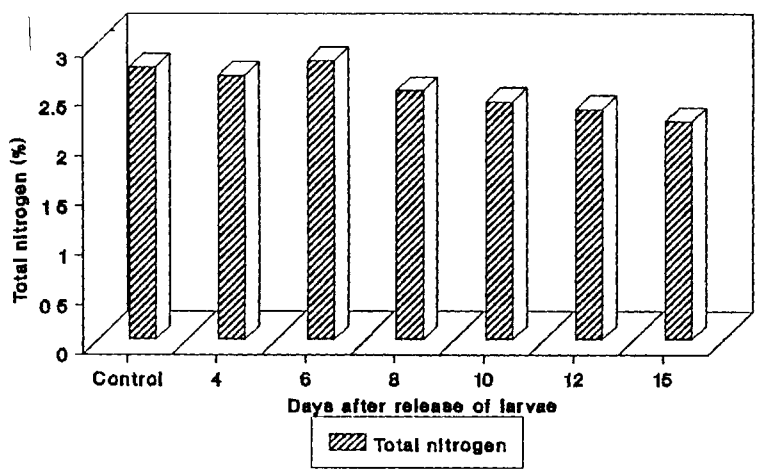


Table 30 Changes in soluble nitrogen content due to larval feeding

Sl No	Number of larvae released	Soluble nitrogen (%)
1	0	0 174 b
2	4	0 202 ab
3	6	0 236 a
4	8	0 209 ab
5	10	0 209 ab
6	12	0 209 ab

Means followed by the same letter are not significantly different at 5% level

Table 31 Changes in soluble nitrogen content after release of larvae

Sl No	Days after release	Soluble nitrogen (%)
1	0	0 178 b
2	4	0 182 b
3	6	0 247 a
4	8	0 206 ab
5	10	0 209 ab
6	12	0 219 ab
7	15	0 222 ab

Means followed by the same letter are not significantly different at 5% level

Fig. 11 Changes in soluble nitrogen content due to feeding of different number of larvae

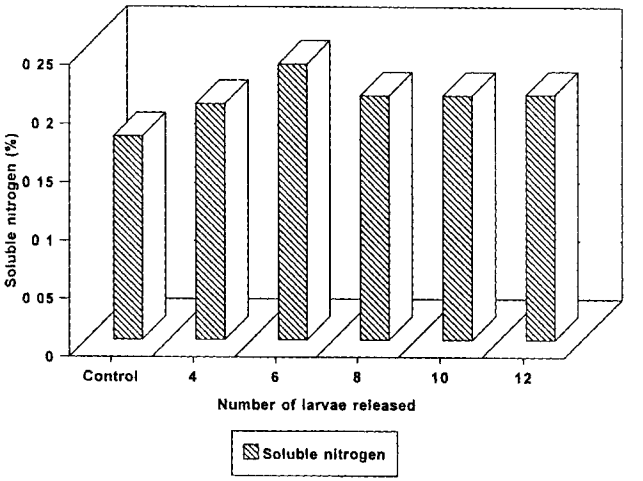
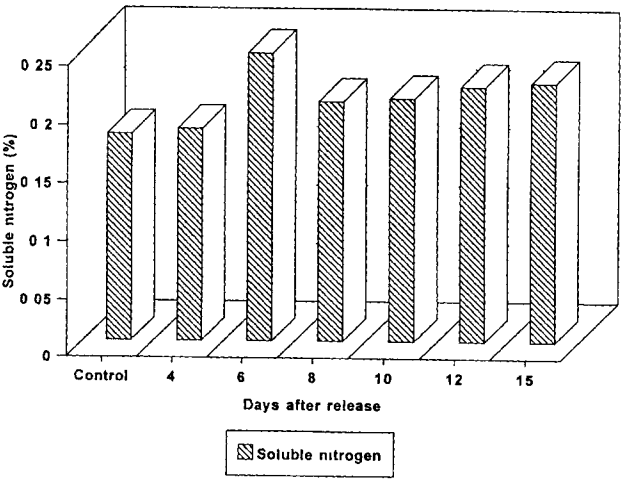


Fig. 12. Changes in soluble nitrogen content on various days after release of larvae



decrease in the per cent of chlorophyll 'a' with increasing insect number The samples drawn before release as well as from 4, 6, 8, 10, 12 and 15 days after release showed a significant decrease in the content of chlorophyll a It was maximum in the control and before release of the insect and it was minimum on 15th day after release of 12 number of larvae

In respect of chlorphyll 'b content also, there was a decreasing trend from 2 086 per cent to 1 026 per cent with increasing larval loads and these were significantly different Maximum content of chlorophyll 'b' was recorded in the control and also before release of the insect the least being on 15th day at the larval load of 12 numbers

Total chlorophyll significantly decreased with increase in larval load from 4 to 12 days after release Total chlorophyll was maximum in control and before release of larvae and the least on the 15th day after release (Plate 13) As the number of larvae increased, the total chlorophyll content showed a decreasing trend

Details of chlorophyll analysis were given in tables 32 and 33 and they were depicted in Fig 13 and 14

4 7 Natural enemies

Various natural enemies of *P pseudoinsulata* were collected and identified

4 7 1 Parasitoids

4 7 1 1 Unidentified hump backed flies (Phoridae Diptera)

Small, minute, yellowish flies characterised by hunched thorax which

Plate 13 Green and insect induced yellow leaves of *C odorata*

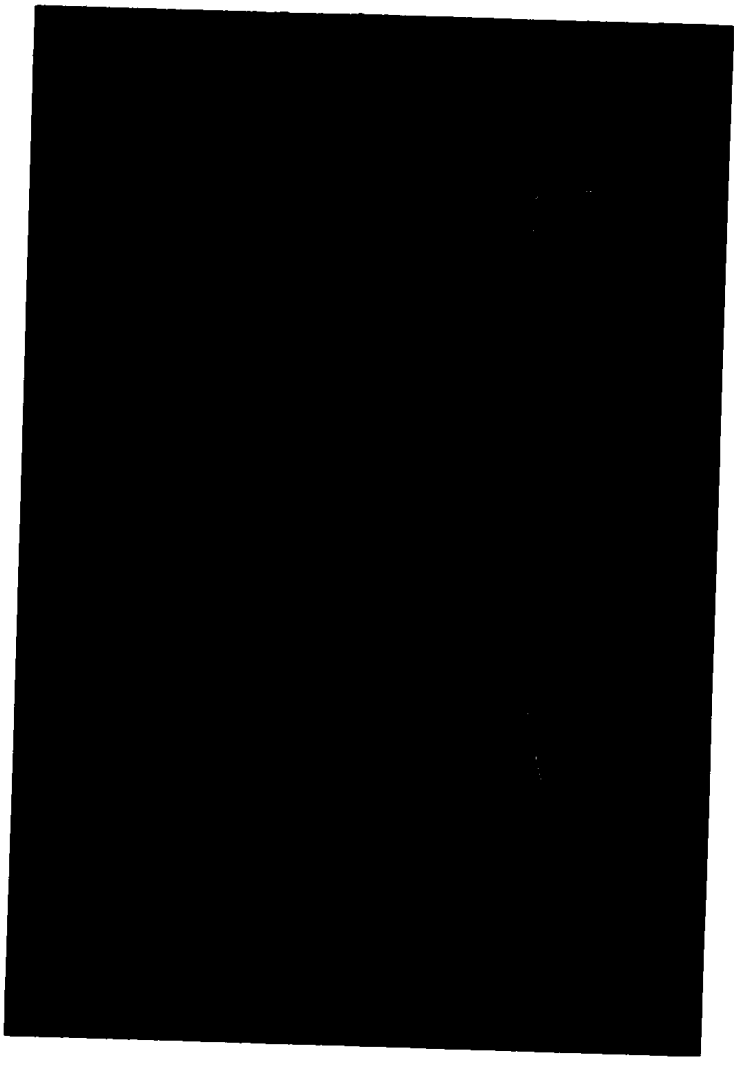


Table 32 Changes in chlorophyll 'a', 'b' and total after release of larvae

Days after release	Chlorophyll 'a' (%)	Chlorophyll 'b' (%)	Total chlorophyll (%)
0	1 467 a	1 652 a	3 119 a
4	0 927 b	1 534 a	2 461 b
6	0 832 c	1 324 a	2 156 c
8	0 756 d	1 202 a	1 958 d
10	0 712 d	1 247 a	1 959 e
12	0 812 c	1 038 a	1 850 f
15	0 646 e	0 944 a	1 590 g

Means followed by the same letter are not significantly different at 5% level

Table 33 Changes in chlorophyll 'a', 'b' and total due to the larval feeding

Number of larvae released	Chlorophyll 'a' (%)	Chlorophyll 'b' (%)	Total chlorophyll (%)
0	1 133 a	2 086 a	3 219 a
4	0 945 b	1 287 ab	2 232 b
6	0 868 c	1 238 ab	2 106 c
8	0 803 d	1 018 b	1 821 d
10	0 853 c	1 008 b	1 861 e
12	0 671 e	1 026 b	1 697 f

Means followed by the same letter are not significantly different at 5% level

Fig.13. Changes in chlorophyll 'a', 'b' and total due to feeding of different number of larvae

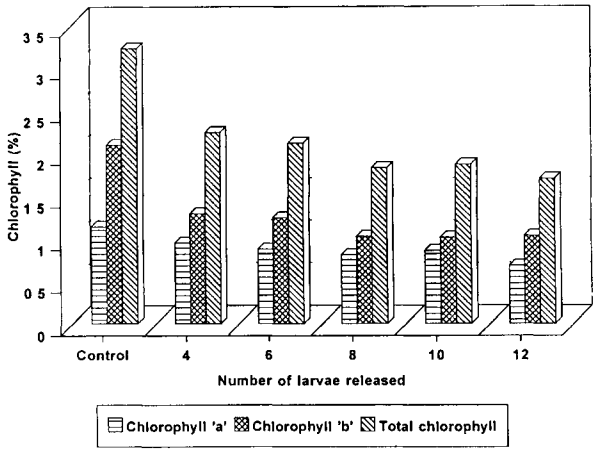
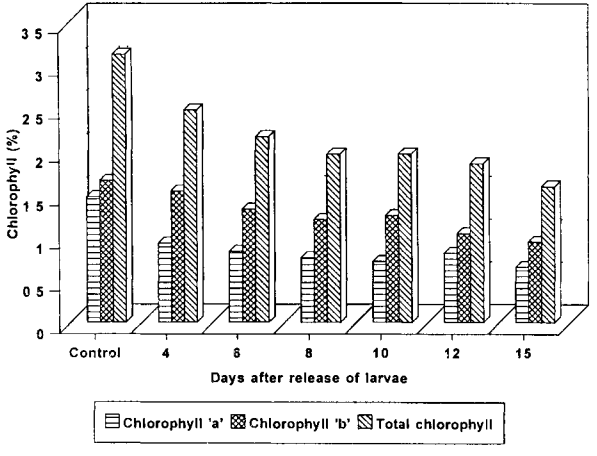


Fig. 14. Changes in chlorophyll 'a', 'b' and total on various days after release of larvae



gives a hump backed appearance (Plate 14) Anterior veins on forewings well developed and other veins are wanting Hind femora laterally flattened The adults are common in most decaying vegetation Egg laying was on the pre pupa of *P pseudoinsulata* and the emerging maggots feed on the internal contents of pre pupa and pupa From a single pupa about 15 maggots were recorded and the parasitised pupae emanated foul smell If the parasitism is severe, it affected the large scale multiplication of the insect causing 2-30 per cent loss

4 7 1 2 *Carcelia* sp (Tachinidae , Diptera)

Medium sized, black flies characterised by well developed hypopleural and pteropleural bristles and prominent post scutellum and short and long bristles covering the abdomen (Plate 15) It is a larval pupal parasite and was collected from field collected caterpillars After pupation of the insect, the maggots of *Carcelia* sp came out making a hole on pupal case of *Pareuchaetes* and pupates outside It was not a severe parasitoid and the incidence of it was rare

4 7 2 Predators

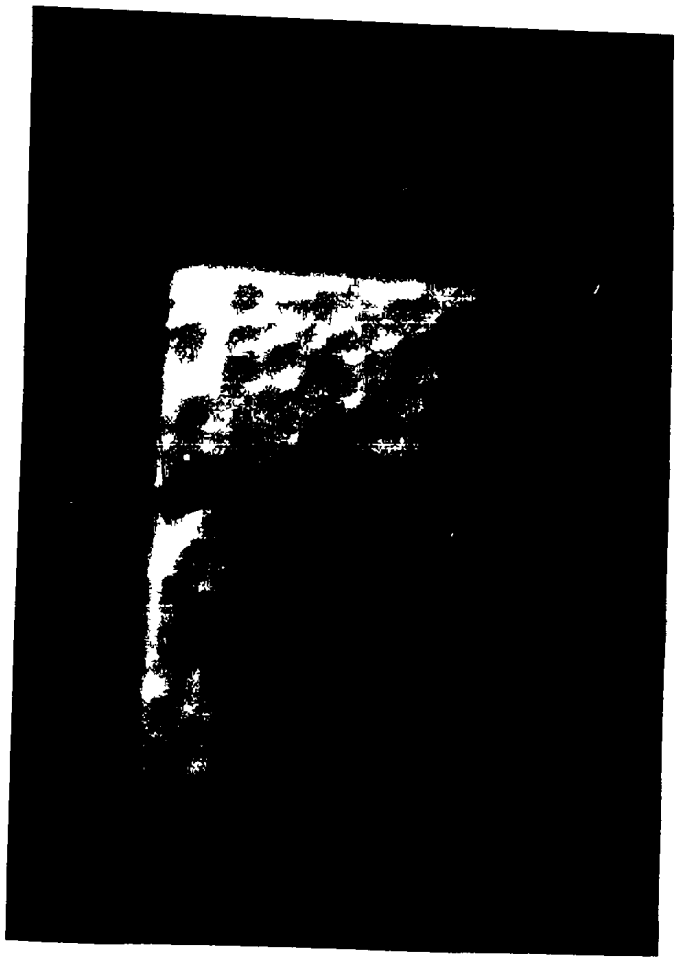
Various predators like birds, spiders and ants were very common in the field

4 7 2 1 Birds

Birds commonly found preying on the insect were Indian Myna *Acridotheris tristis*, Bank Myna *Acridotheris ginginianus*, Indian Bee eater *Merops orientalis* and Black Drongo *Dicrurus adsimilis* In areas frequented by birds they were killed by using air gun The gut of the Indian Myna was dissected out to

Plate 14 Unidentified phorid fly

Plate 15 *Carcelia* sp



determine the detritus and remnants in the viscera But no remnants of the larvae were found

4 7 2 2 Spiders

Spiders mainly *Phidippus* sp also found feeding on the larvae in the field In the laboratory also, spiders fed on young caterpillars inside the rearing cages

4 7 2 3 Ants

Different types of ants were found preying on the larvae in the field The following species of ants were recorded to be predaceous on *P pseudoinsulata*

4 7 2 3 a *Lioponera* sp

Head and abdomen black and shiny Antennae, mandibles, thorax, pedicel and legs red Total length 3 50 mm These were found preying on the larvae and pupae of the insect in the field

4 7 2 3 b *Oecophylla smaragdina* Fabr

These are yellowish red in colour, abdomen with a few short, erect hairs, pubescence very thin The head, thorax legs and abdomen dull and sub opaque Total length 7 11 mm These were also found feeding on the larvae in the field

4 7 2 3 c *Solenopsis* sp

Body reddish yellow, mandibles reddish brown, abdomen with brown markings, body somewhat shiny These are small in size Total length 5 5 mm

4 7 2 3 d *Monomorium* sp

These are yellowish brown in colour, small in size, length 2 5 to 3 mm These are also predatory in nature

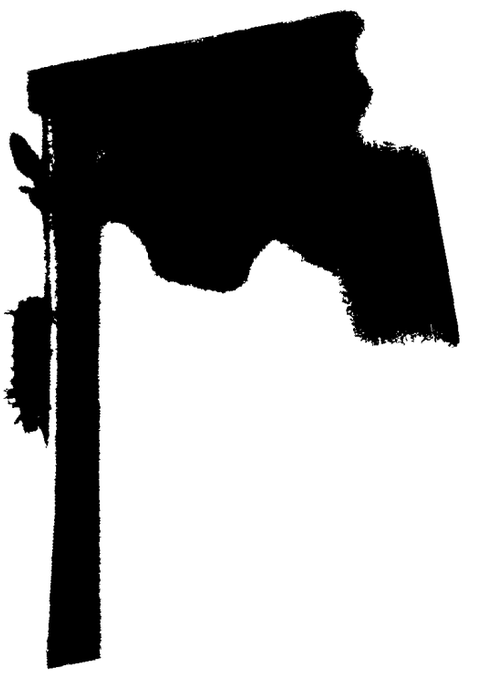
4 7 3 Pathogen

Various pathogens were isolated from dead larvae by preparing wet mounts and smears

4 7 3 1 Nuclear Polyhedrosis Virus

NPV infection was observed in the laboratory as well as in the field In this case, the larvae were found very inactive, retarded in movement and exhibited loss of apitite Shortly before death, the larvae migrated to the highest point available on the plant and then hung head downwards clinging to the plants by prolegs (Plate 16) In the laboratory, larvae were seen hanging from the top of the cage or from the tip of the bouquetes Sometimes dead larvae were seen spread at the bottom of the cage Larval skin became discoloured and oily It became very fragile and brocken by slight touch Haemolymph turbid and the haemolymph and nuclei of the infested cell contained large number of polyhedra which were easily identified under a microscope Virions were rod shaped and these were differentiated from fat droplets by adding a drop of saturated aqueous Sudan III at the edge of the coverslip Then the polyhedra did not stain and the fat droplet stained red These were also identified by placing a small drop of IN NaOH at the edge of the coverslip and allowed to flow through As the alkali penetrated, the polyhedra swelled up and then got dissolved

Plate 16 NPV infected larva of *P pseudoinsulata*



For testing the pathogenicity, clean suspensions of the virus infected larvae were prepared and orally inoculated For larvae, the leaves dipped in the above suspension and for adults, the honey mixed with the suspension were supplied The symptoms were visible from the sixth day onwards In the case of adults the life span came down to 3 to 4 days

NPV infection was very severe in the field and laboratory and 100 per cent devastation of the insect was observed two times in the laboratory In the field also complete disappearance was observed at times and dead larvae were found hanging from the plant tip

4 7 3 2 Bacteria

Bacteria infection was not severe in *P pseudoinsulata* as the NPV infection It was observed in the laboratory that the adults were seen infested by the bacteria *Serratia* sp The abdomen of the adult became very soft and pinkish red in colour About 25 per cent mortality of the adults was caused due to this bacterial infection Pure culture of the bacteria was prepared and inoculated the adults and larvae through feed But no recovery of the bacterium was observed

Discussion

DISCUSSION

Studies were undertaken on the biology, morphometrics, feeding habits, factors affecting fecundity and fertility of *P pseudoinsulata* infesting the weed *C odorata* and also the interaction of the insect development with growth habits of the weed The results of various experiments are discussed below

5 1 Biological studies

5 1 1 Duration of life stages

Incubation period was 5 5 days The total larval duration was 21 30 days with seven successive instars of 2 15, 2 20, 1 95, 3 30, 2 95, 4 45 and 4 35 days duration The pre-pupal and pupal periods occupied 1 5 days and 10 15 days respectively Adult life span was 8 3 days and total life expectancy averaged 46 75 days under Kerala conditions at a mean temperature of 28 4°C In similar studies conducted at Bangalore, India, the incubation period, larval, pre-pupal, pupal and adult longevity were 7, 25 7, 1 7, 11 9 and 10 days respectively, the total develop mental period being 46 3 days (Muniappan *et al* , 1989) There was delayed hatching of eggs and lengthening of life stages which according to them were due to the mean ambient temperature of 26 2°C prevailed during the rearing period At Sabah (Malaysia), egg period was 4 0 days, larval, pre-pupal, pupal, adult and total devel opmental periods were 21 6, 1 8, 10 7 and 38 1 days respectively (Syed, 1977) At Sabah, the durations of the different life stages were lower than the present findings The present investigations reveal that durations of life-stages varies with varying temperature and humidity conditions Cruttwell (1968) recorded a total life cycle of 40-60 days at Trinidad whereas it was 44-64 days in Thailand (Napompeth *et al* ,

1988) These data are close to the result of the present experiment (38 59 days) In Kerala, the total life span recorded earlier by Satheesan *et al* (1987) was 32 42 days Shreeve (1986) reported that temperature had a great role in the speed of development of insects Trivedi and Rajagopal (1991) had experimentally shown a variation in incubation period of the potato tuber moth, *Phthorimoea operculella* Zell from 2 to 28 days within a temperature range of 15°C to 35°C The range of temperature in the present study was 26°C 29°C while that of Satheesan *et al* (1987) in the same locality was higher being 30°C 32°C The variation in the duration of various stages in the present experiments as compared to previous reports are explicable mainly on the basis of the ambient temperature conditions that prevailed in the laboratories during the rearing

In the present studies larvae had seven instars, but very few individuals underwent only six instars At Sabah (Malaysia), some populations of the insect had five larval instars while others had six (Syed, 1977) At Bangalore most of the larvae had six instars and some five (Mumappan *et al* 1989) Shreeve (1986) reported that the larvae of speckled wood butterfly (*Pararge aegeria* L) developed through four or five instars depending upon the temperature He also stated that in the case of *P pseudoinsulata*, the number of instars varied from place to place and according to the climatic conditions in the same place The pattern of larval instars found in the present study could be due to the effect of rearing temperature

5 2 Morphology and morphometrics

The morphology and morphometrics of the insect have been presented in Chapter IV The eggs recorded a mean diameter of 0 969 mm Muniappan *et al* (1989) in his studies conducted at Bangalore (India) recorded eggs of lesser diameter

(0 8? mm) The variations might be due to the influence of leaf nutrient status on the insect under the two environments There were seven larval instars for *P pseudoin sulata* among which the morphological traits and the colouration were quite distinct in the first, four instars and in the other instars the changes were mainly of gross dimensions Morphometrical aspects are reported in the present studies for the first time in India Mumappan *et al* (1989) recorded gross measurement of some stages of the insect and these are found to be generally agree

5 3 Morphometrics of male and female characters

Males and females differed in size and weight in all the stages Males were smaller with slender abdomen than females This is in consonance with the results reported by Satheesan *et al* (1987) on the same insect Ananthakrishnan (1992) recorded that the female insects are always heavier than males and further that this tendency is seen in many larval forms too This is presumably due to higher food consumption and greater nutrient accumulation associated with egg production in females The weight of larvae destined to develop into females and males showed significant variations in respect of their weight, duration of development and gross dimensions Larval characters are being used for sexing in some forms of immature stages In the female larvae there were two paired pits situated on small whitish spots on the ventrolateral surface of the eighth and ninth abdominal segments of *Atlanthus* defoliator *Eligma narcissus indica* Roth (Joseph and Karnavar, 1991) As in the present studies, Ranjith (1981) observed that female larvae of *Pericallia ricini* F were larger in size and weight The longer larval period for females could be an adaptation to facilitate higher leaf consumption to derive more resources and energy for egg production

In the case of female pupa the genital opening was very prominent near the anterior margin of the eighth abdominal segment, while in the male the genetalia were located on the ninth abdominal segment These findings agree with the observations of Torres *et al* (1991), in the same insect According to Joseph and Karnavar (1991) pupal sexing based on the size and location of genital aperture is a more reliable and easier method of sexing in immature stages In the laboratory rearing of natural enemies, the parental sex ratio is a major factor which regulates reproduction and thereby fecundity As sexing of the pupae on the basis of the locations of their genetical aperture is a distinct possibility, the manipulation of the sex ratio of the parental population of *P pseudoinsulata* at the pupal stage intself is rendered feasible In laboratory rearing this is an important step in the realisation of optimal fecundity and progeny production

5 4 Feeding habit of larva

Feeding trials were conducted to assess the relative preference of tender mature, semi yellow and yellow leaves to the larvae of *P pseudoinsulata*

5 4 1 Larval weight

Larval weight was maximum for the last instar in all the cases, irrespective of the type of leaf consumed

When weight of III, IV V, VI and VII larval instars were compared by feeding the larvae with tender, mature, semi yellow and fully yellow leaves, it was found that VII instar had maximum larval weight on consuming mature leaves and the VII instar larvae on consuming tender, semi yellow and yellow leaves had recorded significantly lower weights (Table 13) Higher water and nitrogen contents

in the host plants encourage the best growth of larvae (Waldbauer 1968, Scriber 1977 1978, 1979 a, b, c) In the four types of leaves, the mature leaves had a higher total nitrogen and chlorophyll content and the increase in larval weight in such cases is explicable on the basis of favourable nutritional factors Least larval weight was registered when they consumed yellow leaves Yellow leaves are found tough in nature and with less of total nitrogen and chlorophyll contents Tanton (1962) stated that feeding rates and larval growth were retarded when the larvae were fed on relatively tough turnip, kale and brussels sprout leaves So lower body weight attained on consumption of tough yellow leaves is expected as a result of adverse biophysical and nutritional factors

5 4 2 Leaf consumption

Irrespective of the types of leaves offered higher leaf consumption was found for later instars According to Hiratsuka (1920) and Wolcott (1937) 97 per cent of the total food consumption occurred during the last two instars in *Bombyx* and *Protoparce*, two lepidopterous leaf feeders Ramdev and Rao (1979) reported that food intake of *Achaea janata* Linn on castor increased with age Ranjith (1981) also stated that consumption increased with the age of *Pericallia ricini* Fb larvae These findings are in consonance with the present result

Here tender leaf consumption was much higher than the mature leaf consumption in the I instar The preference of tender leaves in the early stage of the larvae thus established According to Muniappan *et al* (1989) the larvae of *P pseudoinsulata* consumed the mature leaves, only in the absence of tender leaves From the II instar onwards maturity of the leaf is not found to be a factor that determines leaf consumption

When semi yellow and yellow leaves were offered to the I instar larvae, they did not feed at all and died due to starvation This shows that these kinds of food material were not accepted This is explicable on the basis of presence of phagodeterrents or absence of phagostimulants in the leaves which have turned partially yellow and yellow From the nutritional point of view also the leaves were found to be inferior Mandibles of the early stages larvae are not fully developed to feed upon tough natured leaves and hence lack of feeding of I and II instar larvae on these leaves could be due to this reason Colour of substrates also influence host selection behaviour of phytophagous insects (Maxwell and Jennings, 1980) Maruta ni and Muniappan (1988) reported the toughness and low nitrogen content of semi-yellow and yellow types of *Chromolaena* leaves Gross changes from the normal texture and colour of leaves could be the reasons for not accepting these leaves as feed in the early, delicate stages of the larvae But from the III instar onwards the larvae were found to feed on such leaves in no choice situations According to Marutani and Mumappan (1988) the caterpillars favoured green leaves in both young and older stages, but when they were in the third stage or later instars they also consumed the partially yellow leaves The above observation is in conformity with the present studies

5 4 3 Consumption index

The consumption indices were found to decrease as age of larvae ad vanced and thus early instars recorded high indices for all the four kinds of leaves Ramdev and Rao (1979) observed a decreased consumption index as the age in creased in the case of castor semilooper *Achaea janata* Linn Dandapani and Bala

subramaman (1980) stated that consumption index decreased with the increase in age in *Heliothis armigera* Hubner These reports are in general consonance with the present findings that the consumption index decreased with larval growth

The highest consumption index was for the IV instar larvae when they consumed semi yellow leaves (Table 14) Consumption indices were also higher when the larvae consumed yellow leaves Yellow and semi yellow leaves are low in total nitrogen and chlorophyll contents and therefore to get adequate level of nutri ents increased feeding must have been resorted to by the larvae as a compensatory activity for nutritional satiation However, eventhough there was more feeding weight gain in larvae was less when they fed the two types of leaves as compared to tender and mature leaves This might be due to the qualitative inadequacy of the yellow and semi yellow leaves as compared to the tender and mature leaves

5 4 4 Weight increase of larval instars

The rate of increase in larval weight was higher in the later instars This shows that food consumption and utilisation are improved as the larvae grows This is expected in normal growth cycles

5 4 5 Relative growth rate

Relative growth rate of larvae was higher during IV to V stage when they consumed mature, semi yellow and yellow leaves Muniappan *et al* (1989) also recorded maximum growth rates in IV and V instars When tender leaves were supplied, the relative growth rate was higher during I to II instar, and this shows that for the I and II instar larvae tender leaves were the most suitable food material (Table 6)

Relative growth rate was maximum when the larva grew from the IV to V instar on mature leaf diet and it was the least when the larva grew from the VI to VII instar on semi yellow leaf diet (Table 15) The present findings are in consonance with that of Marutani and Mumappan (1988) who recorded that the growth rate of the larvae was greater when they consumed green leaves as compared to feeding on yellow leaves

Eventhough the larval growth and development occurred in a normal manner when they consumed partially yellow and fully yellow leaves from the III instar onwards, adult emergence was reduced considerably Most of the adult emergents were found to be malformed with crinkled wings This phenomenon might be due to severe nutritional imbalances in yellow leaves characterised by low total nitrogen, increased soluble nitrogen and less chlorophyll contents (Table 28 30 and 32) Marutani and Muniappan (1988) also reported similar results According to Haukioja and Niemela, 1976, 1977, Schultz and Baldwin, 1982, Edwards and Wratten, 1983 and Edwards *et al* , 1985, in several plant species, previous non lethal insect infestation can lead to changes in the resistance and palatability of plants The growth of larvae of the geometrid moth, *Epirrita autumnata* was retard ed when they were fed on previously grazed birch trees (Haukioja and Hanhimaki 1984) and larvae of *Spodoptera littoralis* and *Orgyia antiqua* found damaged birch (*Betula* spp) less palatable than undamaged leaves (Wratten *et al* , 1984)

Colour and shape of plants indirectly influence the host selection be haviour of phytophagous insects (Maxwell and Jennings, 1980) In the present studies the larvae were constrained to feed on yellow leaves in the absence of green

leaves It is to be recalled that on yellow *Chromolaena* leaves, feeding rhythm was of an irregular nature from III instar onwards In yellow leaves the presence of dark coloured larvae will be more striking and this situation is likely to be favourable to the natural enemies due to improved visual stimulus A decline in field population of the insect is therefore thus quite likely

5 4 6 Effect on larval, pupal and adult periods and weights when fed tender mature, semi yellow and yellow leaves

When tender and yellow leaves were consumed, the larval period was longer than when mature leaves were consumed (Table 16) Even though the early instars preferred the tender leaves, the quick development of the different stages took place when the larvae consumed mature leaves This may be due to insufficient amounts of nutrients available in tender and yellow leaves The present results showed decreased nitrogen and chlorophyll contents in tender and also on yellow leaves

The extention of larval duration when fed tender and yellow leaves could be an adaptation to get adequate nutrients for proper growth and development Purohit and Deshpande (1991) reported that larval period of *Heliothis armigera* Hubner was significantly reduced when they fed sunflower leaves having high nitrogen content

An analysis of the larval weights show that it was maximum when mature leaves were consumed in all the stages and minimum when yellow leaves were consumed (Table 17) The larvae which consumed tender leaves recorded less weight than those which fed mature leaves Marutani and Mumappan (1988) found that the duration of instars of the insect increased when they fed yellow leaves and

according to them it may be due to insufficient amounts of nutrients available for caterpillars consuming yellow leaves The irregular rhythm of feeding on yellow leaves during day time is perhaps an adaptation for extending the consumption period when unsatisfactory food was available The present results are in confirmity with the trend reported by Marutani and Muniappan (1988)

5 4 7 Leaf area and leaf weight consumption

The larvae consumed maximum quantity of mature leaves Since the mature leaf is most suited food, more leaf weight consumption can be expected here Leaf area consumption was maximum for tender leaves In order to get sufficient nutrients, bulk feeding became necessary and the larval duration was extended for the purpose

5 5 Studies on fecundity and egg hatchability

5 5 1 Effect of sex ratio

Evaluation of three parental sex ratios showed that maximum fecundity was realised for 1 1 female male ratio, followed by 1 2 and 2 1 ratios in that order (Table 20) According to Danthanarayana and Gu (1991), virgin females of *Epiph yas postvittana* (Tortricidae , Lepidoptera) were capable of egg laying, but mating stimulated and accelerated oviposition and the mated females laid twice as many eggs as unmated ones Regarding viability of eggs, it was highest for 1 1 parental sex ratio followed by 1 2 ratio The present studies showed that for the realisation of the reproductive potential of females, parental sex ratio at optimal level is an important criterian and further that the ratio of 1 1 is definitely better in this context When more or less males among the parents, the fecundity showed reduction and

this might be due to the competition of the individuals which finally adversely influence the process of successful mating and their proper fertilization of ova In the case of *E postvittana* also Boggs and Gilbert (1979) found that the optimal sex ratio is 1 1 for population growth, fecundity and fertility

5 5 2 Effect of temperature-humidity regimes

The fecundity and hatching percentage were significantly higher at 25°C temperature and 75 per cent RH Joy *et al* (1993) found that above 30°C, the hatching percentage of *P pseudoinsulata* eggs was very low and this lends support to the present results (Table 21)

5 5 3 Effect of food combinations on fecundity

Assessment of the influence of various food combinations on the adult fecundity showed that honey + water (1 1) fortified with 0 1 per cent sodium chloride gave maximum egg output, next in the order of efficiency was honey + water (1 1) fortified with 0 1 per cent sodium chloride and 0 4 per cent vitamin E However the results were statistically not significant and the fecundity levels were on par with the treatment in which water alone was supplied to the females (Table 22) It can thus be concluded that adult diet has no influence on fecundity This is explainable on the basis of provigenic reproduction in which the adults emerge with a full complement of developed ova Adult nutrition is not therefore, of any consequence in the realisation of egg production potential The report of Oceterubio (1982), in the case of *S littoralis*, the presence or absence of food had no effect on its fecundity corroborates the present results

Napompeth (1990) suggested to incorporate sodium chloride to diets of both adults and larvae of *P pseudoinsulata* to improve the fertility The present results showed that incorporation of sodium chloride in the adult diet did not bring about improvement in fertility of eggs

5 5 4 Interaction between sex-ratio and temperature-humidity regimes

Interaction between sex ratio and temperature-humidity regimes revealed that at 1 1 ratio and 25°C and 75 per cent RH, the adults gave maximum fecundity and viability This shows that within the range tested, the temperature - humidity preferendum is 25°C and 75 per cent RH for the realisation of fecundity and fertility potential of the insect The influence of temperature and humidity on insect reproduction has been well established At adverse conditions particularly beyond the zone of effective temperature the motility and viability of the sperm and viability of ova might be adversely affected and under such conditions, impairment of fecundity and fertility is quite expected According to Oceterubio (1982) *S littoralis* showed beneficial effects on fecundity and fertility at optimum temperatures of 21-25 5°C

5 5 5 Interaction between sex ratio and food combinations

Adult fecundity was higher in the sex ratio of 1 1 under various food combinations The relative importance of the sex ratio as a factor regulating fecundity is brought out m the present study Gunn and Gatehouse (1985) stated the presence of sucrose in the adult diet increased the fecundity of African army worm *Spodoptera exempta* considerably than exclusive water diet However m the present study the results are divergent Such variations in the adult nutritional requirement among different species of Lepidoptera are quite possible

5 5 6 Interaction between food combinations and temperature-humidity regimes

Significantly higher fecundity was recorded at 25°C and 75 per cent RH when adults were fed honey + water (1 1) fortified with 0 1 per cent sodium chloride But the same adult food gave a low fecundity at 30°C temperature and 60 per cent RH The nature of interaction substantiates that adult food is not a critical factor regulating fecundity The adverse effect of higher ambient temperature of 30°C and lower RH at 60 per cent is clearly brought out in the present studies

The egg hatch was significantly higher in all the food combinations except water at 25°C and 75 per cent RH than at 30°C and 60 per cent RH When water alone was given, there was a reduction in hatching of eggs (Table 25) It is probable that the foods other than water provided some kind of olfactory stimuli which promoted courtship, mating and successful fertilization of eggs

5 5 7 Interaction of sex ratio, temperature-humidity regimes and food combinations

The nature of the three level interaction showed that the female-male sex ratio of 1 1 at 25°C and 75 per cent RH gave significantly higher fecundity for all the food combinations But, the egg output of females at 1 1 sex ratio was considerably reduced at 30°C and 60 per cent RH, thereby indicating the deleterious effects of this particular physical environment on fecundity The viability of eggs was also adversely affected at all sex-ratios under this temperature-humidity combination (Tables 26, 27)

As the adult foods other than water were found to be useful to improve the egg hatch at optimal ambient environment, it would be advantageous to resort to such feeding techniques

5 6 Metabolic changes in the plant due to the feeding of the insect

5 6 1 Total nitrogen and soluble nitrogen

The total nitrogen content in the plant on the 4th, 6th, 8th, 10th, 12th and 15th days after releasing 0, 4, 6, 8, 10 and 12 numbers of III instar larvae showed significant differences (Table 28) The total nitrogen was maximum on sixth day and when four larvae were released per cage From eighth day onwards, nitrogen showed a declining trend with increase in the number of larvae and it was least on 15th day after release of twelve larvae per cage The increase in nitrogen up to 6 days following insect feeding may be the outcome of initial compensatory plant response to recoup from debilitation through enhanced absorption of the nutrients, but subsequent fall in nitrogen could either be due to cessation of the compensatory activity by severe debilitation or metabolic processes According to Mooney *et al* (1983) nitrogen is highly mobile and readily metabolised and this is an important element which contributes to metabolic changes of plants following insect attack An increase of nitrogenous compounds in insect defoliated tobacco plants was recorded by Baldwin (1988) The results reported in the present studies are in general agreement to the findings of Marutani and Muniappan (1988) who recorded 2 99 per cent total nitrogen in green leaves which on feeding by *P pseudoinsulata* got reduced to 2 72 per cent as the leaves turned yellowish

The soluble nitrogen content showed an increasing trend with increasing number of larvae and days after release, but the trend was not significant (Table 30 and 31) According to Marutani and Muniappan (1991) nitrate nitrogen was 54 2 μg/g in green leaves and 911 4 μg/g in yellow leaves As a result of feeding, foliar yellowing is expected to progress over a period of time and according to the finding of Marutani and Muniappan (1988) the total nitrate nitrogen content would show definite upward swing However in the present studies, such definite trends were not descernable and this is explicable on the basis of the soil-plant interaction in the present experimental milieu as compared to that of other studies It is also possible that the biotic stress from *P pseudoinsulata* in the present situation did not trigger a defensive adaptation of chemical nature in infested plants based on nitrites formed as suggested by Sajise *et al* (1974) Sajise *et al* (1974) recorded a high amount of nitrate in the leaves regrown from clipped plants According to them when nitrate is present at high levels, it is reduced to nitrite which could be toxic to animals and this situation may be a defensive adaptation in plants Ohmart *et al* (1987) indicated that the first instar larvae of *Paropsis atomaria* (Chrysomelidae, Coleoptera) fed on *Eucalyptus blakelyi* leaves with low nitrogen were not able to initiate feeding and died due to leaf toughness In the present experiment also indication is that the nutritional deficiency imposed by low nitrogen and the biophysical constraints such as leaf toughness could be the probable defensive reactions in *C odorata* rather than the toxic effects of higher nitrate contents as hypothesised by Sajise *et al* (1974) In the present experiments leaves regrown from clipped plants were not analysed for nitrate nitrogen content and hence the discussion of the results with reference to Sajise *et al* (1974) is not very relevant

5 6 2 Chlorophyll

Present investigations on chlorophyll assay showed that there is significant reduction in chlorophyll content due to feeding of the larvae

The chlorophyll content got reduced significantly in leaves with increase in the larval density and as feeding progressed over successive days (Table 32 and 33) Thus on the fifteenth day after release, chlorophyll content was observed to be the least when 12 larvae per cage were released Similar results were observed by Marutani and Muniappan (1991) and according to them chlorophyll content was much lower in insect infested leaves than leaves from artificially defoliated plants and the artificial defoliation could not produce the same type of yellow leaves caused by the insect attack Mc Fadyen *et al* (1991) also reported the changes in leaves due to feedmg of insect and found that the amount of chlorophyll and rate of photosynthesis were reduced in yellow leaves

In general, feeding of *P pseudoinsulata* on *C odorata* alters the plant metabolism and this change leads to unfavourable nutritional profile of leaves causing low acceptance by the insect as it feeds The unsuitability of yellow leaves is reflected in the retarded development of the insect when reared on such materials It is to be recalled that the I and II instar larvae reared on yellow leaves did not survive

5 7 Natural enemies of *P pseudoinsulata*

The unidentified phorid was found to occur as a common parasitoid of *P pseudoinsulata* larvae causing about 2 30 per cent loss Joy *et al* (1993) also reported the occurrence of these flies as larval parasite

The predatory component of the natural enemy complex was more dominant Birds such as *A trists, A gingmianus, M orientalis* and *D adsimilis* were found as predators of adults and caterpillars in the field Esguerra *et al* (1991) observed bird preying heavily on adults, larvae and eggs of the insect Joy *et al* (1993) suspected insectivorous birds caused reduction in larval population in Kerala

Spiders mainly *Phidippus* sp were found feeding on the larvae in the field Esguerra *et al* (1991) also reported that spiders preyed on eggs and larvae of the insect

Among the ants found to predate on the insecet, *Lioponera* sp , *O smaragdina* Fabr , *Solenopsis* sp and *Monomorium* sp were more common in the field Sankaran and Sugathan (1974) suspected that the failure of *P pseudoinsulata* to establish in India was due to detrimental activities of more than one species of predatory ants Simmonds (1976) and Singh (1980) have stated that predatory ants were the primary cause for non establishment of the insect in India Seibert (1989) also found the predation by ants mainly *S geminata* F Marutani and Mumappan (1991) also reported the predaceous nature of *Solenopsis* sp on the insect

The nuclear polyhedrosis virus infection was severe in laboratory as well as in fields and at times heavy mortality ranging from 80 100 per cent of the field larval populationswere recorded In Trinidad also NPV was recorded as the major constraint (Chacko and Narasimham, 1988) According to Joy *et al* (1993) NPV epidemics frequently occurred both in laboratory and field conditions in Kerala Joy *et al* (1993) reported bacterial infection under laboratory conditions, but in the present studies such infections were not detected

A critical appraisal of the failure of *P pseudoinsulata* to establish in Kerala (Joy *et al* 1993) in the light of the present findings brings out the involvement of adverse summer environments characterised by high temperature low humidity situations as the most likely causative factors Thus in summer, when the insect populations dwindle considerably due to the abiotic stresses, it is probable that the biotic stress from predators, parasitoids and NPV infection might have further aggravated the adverse situation leading to population decimation

Stragetic shifts in release programmes to overcome the above constraints can be suggested in the light of the emerging findings In Kerala, the period from August to February is more favourable for the survival and development *P pseudoinsulata* and hence sustained releases preferably of mated adult moths during this period would be advantageous in terms of its successful establishment The unsuitability of yellow and partially yellow leaves to the early instar larvae is another problem which requires solution under post release field situations In such circumstances, releases of late instar larvae (IIIrd and beyond) would be required to sustain the level of stress from the bio control agent During summer months, releases are to be made in areas where the weed *C odorata* occurs in rubber plantation and in such other niches where the micro climate is relatively more favourable due to cooler conditions

The findings that the maintenance of the parental sex ratio at 1 1 and rearing the insects at preferred temperature humidity levels (25°C 75 per cent RH) cause considerable improvement in the fecundity and fertility of *P pseudoinsulata* are very valuable to augment laboratory stock cultures of the insect to cope up with inundative release requirements

Summary

SUMMARY

Studies were undertaken in the College of Horticulture, Vellanikkara during 1990-'93 on the biology, morphometrics, feeding habits, factors affecting fecundity and fertility of *Pareuchaetes pseudoinsulata* King and Robinson (Arctiidae, Lepidoptera) and also the response of the weed host *Chromolaena odorata* Linn to insect infestation

In studies on the biology of *P pseudoinsulata*, the mean durations of various developmental stages were found to be 5 5 ± 0 087 days for the eggs, 21 30 ± 0 327 days for the larvae (seven instars), 1 5 ± 0 096 days for pre-pupa and 10 15 ± 0 221 days for pupae The adult life span was 8 30 ± 0 128 days and the total life cycle occupied 46 75 days

The morphometrics of the various developmental stages have been worked out Among the seven larval instars, variations in the morphological traits, especially the colouring pattern were more distinct in the first four instars while in the subsequent instars, the changes were mainly in respect of the gross dimensions Sex differentiation in pupal stage was found to be possible on the basis of the position of genital openings on the 8th and 9th abdominal segments

In laboratory studies to assess the relative preference of tender, mature, semi-yellow and yellow leaves of the larvae, it was found that the maximum larval weight was registered for the VII instar which fed mature leaves The first instar larvae showed distinct preference to tender leaves as compared to mature leaves The

first and second instar larvae did not feed on semi-yellow and yellow leaves and they died of starvation when these types of leaves were offered for feeding From the II instar onwards the larvae developed on tender and mature leaves without showing any preference

The Consumption indices decreased as the age of larvae advanced and thus early instars recorded high indices for all four types of leaves Relative growth rate (RGR) was higher in the IV to V stage when the caterpillars consumed mature, semi-yellow and yellow leaves, but during I to II instar the RGR was higher in larvae which consumed tender leaves Maximum Relative growth rate was realised during the transition of larvae from the IV to V instar on mature leaf diet

From the III instar onwards the larval growth and development took place even when fed semi yellow and yellow leaves, but in such cases adult emer gence was curtailed considerably The adults showed malformed and crinkled wings Larval duration was found to be extended on consumption of yellow and tender leaves

Highest fecundity was obtained when the parental sex-ratio of moths was kept at 1 1 level followed by 1 2 ratio and 2 1, in that order Regarding viabili ty of eggs, it was highest for the parental sex-ratio of 1 1, followed by 1 2

The temperature-humidity regimes showed cosinderable influence on fecundity and fertility of eggs The fecundity and percentage egg hatchability were significantly higher at 25°C and 75 per cent RH as compared to 30°C and 60 per cent RH

It was found that adult nutrition did not influence the fecundity However when adults were fed water alone the egg hatching was significantly lower than other kinds of adult food The implication of these results in laboratory rearing have been discussed

The three level interaction showed that the female male sex ratio of 1 1 at 25°C and 75 per cent RH gave significantly higher fecundity for all the food combinations than 1 2 and 2 1 sex ratios The temperature humidity regime of 30°C and 60 per cent RH considerably reduced fecundity and egg viability in all the sex ratios and for all the food combinations The unfavourable ambient environments characterised by high temperature low humidity situations for the insect have thus been identified

The total nitrogen content in leaf samples showed significant variations on 4th, 6th, 8th, 10th, 12th and 15th days after releasing variable number of larvae Total nitrogen was maximum in the leaves, on the sixth day of release of four larvae per plant Leaf nitrogen showed a declining trend when the larval load per plant was increased from the eighth day of release onwards The nitrogen content was the least on 15th day after release of twelve larvae

Soluble nitrogen content showed an increasing trend with increasing number of larvae and days after release

Chlorophyll content in the leaves got reduced significantly with increased larval population load in plants and with the passage of time of confinement of larvae

The natural enemies of *P pseudoinsulata* consisted of avian fauna, spiders, ants and parasitoids Birds usually preying on the insect were *Acrid otheris tristis, Acridotheris ginginianus, Merops orientalis* and *Dicrurus adsimilis* The predatory ant species were identified as *Lioponera* sp , *Oecophylla smaragdi na*, *Solenopsis* sp and *Monomorium* sp An unidentified phorid fly and *Carcelia* sp (Tachinidae) were recorded as parasitoids of the larvae

The nuclear polyhedrosis virus infection of the larvae was found to cause occasional problems in laboratory as well as in field cultures Strategic shifts in release programmes to overcome the various constraints have been suggested in the light of emerging conclusions

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ABSTRACT

Studies were undertaken on the biology, morphometrics, feedmg habits, factors affectng fecundity and fertility of *Pareuchaetes pseudoinsulata* King and Robinson (Arctiidae Lepidoptera) and also the plant response of the weed host *Chromolaena odorata* L at the College of Horticulture, Vellanikkara during 1990-'93

The morphometrics and morphology of the various immature stages and adults have been described The total life-cycle of *P pseudoinsulata* took a total of 46 75 days and the various developmental stages lasted for 5 5 days in eggs, 21 30 days for larvae (seven instars) 1 5 days for pre-pupa and 10 15 days for pupae at a mean ambient temperature of 28 4 °C

In feeding trials to assess the relative preference of tender, mature, semi yellow and yellow leaves of *C odorata*, it was found that the I instar larvae showed distinct preference to tender leaves as compared to mature leaves The I and II instar larvae did not feed on semi-yellow and yellow leaves and they died of starvation when these types of leaves were offered for feeding Consumption indices decreased as the age of larvae advanced and thus early instars consuming all the types of leaves recorded high indices The rate of increase in larval weight gain was higher in later instars (VI and VII) Caterpillars feeding on mature, semi-yellow and yellow leaves showed higher Relative Growth Rate during IV to V stage, but during I to II stage, a high RGR was seen on larvae which fed tender leaves Yellow leaf diet for late instar larvae adversely affected their development and adult emergence

Highest fecundity was recorded when the parental sex ratio of moths was kept at 1 1 level followed by 1 2 ratio and 2 1 in that order Egg production and viability were significantly higher at 25°C and 75 per cent RH as compared to 30°C and 60 per cent RH Adult food did not show any in fluence on fecundity but in respect of improvement of egg viability the treat ments were advantageous

Total nitrogen content in leaves was maximum on the sixth day of re lease of four larvae per cage Leaf nitrogen showed a declining trend when the larval load per plant was increased from the eighth day of release onwards Soluble nitro- gen content in leaves showed an increasing trend with increase in larval load per plant, but this however failed to reach significant levels Chlorophyll content in leaves got reduced significantly at increased larval population loads and with pas sage of time of confinement

The natural enemies of *P pseudoinsulata* consisted of avian fauna, spiders and ants and parasitoids Predatory species of ants recorded in associa tion with the insect included *Lioponera* sp *Oecophylla smaragdina* Fabr *Solenopsis* sp and *Monomorium* sp Occasionally NPV infection occurred in the laboratory as well as in field cultures causing substantial mortality

The implications of the various findings in reorienting the biocontrol strategies involving *P pseudoinsulata* against *C odorata* have been discussed