STUDIES ON SEASONAL OCCURRENCE, BIOLOGY AND CONTROL OF CITRUS BUTTERFLY, *Papilio demoleus* Linnaeus (Papilionidae : Lepidoptera)

By

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CERTIFICATE

Mrs. V. LAKSHMI NARAYANAMMA has satisfactorily prosecuted the course of research and that the thesis entitled **"STUDIES ON SEASONAL OCCURRENCE, BIOLOGY AND CONTROL OF CITRUS BUTTERFLY, *Papilio demoleus* Linnaeus (Papilionidae - Lepidoptera)"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been previously submitted by her for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON SEASONAL OCCURRENCE, BIOLOGY AND CONTROL OF CITRUS BUTTERFLY *Papilio demoleus* Linnaeus (Papilionidae - Lepidoptera)"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the Acharya N.G.Ranga Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Mrs. V. LAKSHMI NARAYANAMMA** under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All the assistance and help received during the course of investigations have been duly acknowledged by the author of the thesis.

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V. Lakshmi Narayanamma

(V. Lakshmi Narayanamma)

DECLARATION

I **Mrs. V. LAKSHMI NARAYANAMMA** do here by declare that thesis entitled **"STUDIES ON SEASONAL OCCURRENCE, BIOLOGY AND CONTROL OF CITRUS BUTTERFLY, *Papilio demoleus* Linnaeus (Papilionidae - Lepidoptera)"** submitted to Acharya N.G. Ranga Agricultural University for the degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that the material contained in this thesis has not been published earlier in any manner.

V. Lakshmi Narayanamma

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ABSTRACT

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Title of the thesis	:	**STUDIES ON SEASONAL OCCURRENCE, BIOLOGY AND CONTROL OF CITRUS BUTTERFLY, *Papilio demoleus* Linnaeus (Papilionidae: Lepidoptera)**
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Studies on seasonal abundance of citrus butterfly, *Papilio demoleus* Linnaeus were undertaken on Sathgudi sweet orange and Tenali acid lime during July, 2000 to June, 2001. On both the hosts, butterfly population was negligible during July and August, 2000 and from April to June, 2001. Pest incidence was first initiated from second fortnight of August on sweet orange and from first fortnight of September on acid lime. Pest activity was severe during October-December and first fortnight of January on sweet orange and during November to January on acid lime. Peak activity periods synchronised with the emergence of new foliage. Correlation co-efficient values were worked out in relation to weather factors and larval population showed negative and significant correlation between pest population and maximum and minimum temperatures, while positive significant correlation with relative humidity and positive non-significant correlation between pest population and rainfall on both hosts.

Biology studies of citrus butterfly, *Papilio demoleus* Linnaeus were carried out on three hosts viz., Sathgudi sweet orange, Tenali acid lime and curry leaf separately and it showed variation in the duration and morphometrics of all the stages. The mean duration of the different stages viz., the egg period of 2.91, 3.41 and 3.02 days, larval period of 8.90, 16.96 and 16.47 days on three hosts respectively. The total life cycle was completed in 20.99, 31.16 and 28.69 days on sweet orange, acid lime and curry leaf respectively. Sathgudi offered itself to be the more preferable host for *P. demoleus* by completing the growth and development in shorter period compared to acid lime and curry leaf.

The order of priority based on host preference lies

Sweet orange > Curry leaf > Acid lime

During the period of study, three braconid parasitoids viz., *Apanteles papilionis* Viereck, *Apanteles* sp. and *Bracon hebetor* were found associated with larval population of butterfly. The parasitisation was negligible on both sweet orange and acid lime in the months of July and August, 2000 and April to June, 2001. Highest rate of parasitisation was observed during November to January on sweet orange and from second fortnight of November to January on acid lime. Peak periods of parasitisation synchronised with the peak periods of pest activity. Correlation co-efficient values were worked out among weather factors and per cent parasitisation, showed negative and significant correlation with temperatures (maximum and minimum), while positive significant correlation with relative humidity and positive non-significant correlation between per cent parasitisation and rainfall on both hosts.

Studies on the feeding response of *Papilio* larval population on two year old Sathgudi host plants revealed that host plant subjected to one larva caused significantly lowest damage by consuming 41.67 per cent leaf area at the end of its developmental period followed by two and three larvae recording 59.5 and 71.33 per cent damaged leaf area respectively. Damage severity increased with increase in the number of larval population, chiefly the treatments four and five larvae per plant resulted in extensive damage to the plants consuming 80.0 and 92.34 per cent leaf area respectively.

Bio-pesticides viz., *Bacillus thuringiensis* var *Kurstaki* tested in three different concentrations (0.0025%, 0.005% and 0.0075%), *Beauveria bassiana* (1 g/lit), neem oil (0.5%), neem seed kernel extract (5%) and azadirachtin (0.005%) were evaluated against citrus butterfly under field and laboratory conditions. In the field experiment, all the three concentrations of B.t were highly effective recording 83.7, 89.65 and 89.93 per cent reduction in larval population respectively over untreated check. B.t was followed by botanicals viz., neem seed kernel extract, neem oil and azadirachtin with 65.76, 64.8 and 62.8 reduction respectively. *Beauveria bassiana* was found next in the order of efficacy. However, in laboratory experiment B.t found to be the most effective treatment followed by neem oil and *Beauveria bassiana.*

Chapter - I

Introduction

CHAPTER - I

INTRODUCTION

The genus "Citrus" is unique in its diversity of forms and no other fruit crop can parallel to it. Citrus fruit crops possess greater adaptability to different climatic conditions and hence, are grown with equal success in tropical and subtropical as well as in some favourable parts of the temperate regions of the world. The genus includes a large number of species and cultivars among which limes, lemons, oranges, mandarins, grape fruits and pummelos are very popular.

They are highly regarded for their nutritive value and economic significance. Citrus fruits have a prominent place possessing certain good attributes like availability throughout the year, source of minerals, vitamins and other essential elements, besides being a rich source of Vitamin C, that are required for human health.

Citrus industry is the third largest one in the world since the crop occupies about six per cent of the total area under fruit production. Citrus occupies a place of considerable importance in the fruit economy of India and is only next to mango and banana, with an estimated production of 3.79 million tonnes of fruits and with an area coverage of 0.45 million ha.

The annual production was 29.79 lakh tonnes of fruits with an estimated productivity of 8.06 tonnes per hectare (Yadav, 1997). Commercially mandarins, sweet oranges and acid limes were most important groups sharing 41, 23 and 23 per cent respectively of the citrus production in the country. During the last 35 years, there was a significant growth (about 5 times) in area expansion, from 90.7 thousand ha in 1961 to 454.1 thousand ha in 1996 (Ghosh, 1999).

In India, Andhra Pradesh occupies a prominant place with an area of 62,873 hectares and annual production of 9,43,140 tonnes of citrus fruits (Directorate of Horticulture, 1995-96). The important species cultivated in the state are sweet orange and acid limes. The other important states for citrus cultivation are Maharashtra, Karnataka and Punjab. In Andhra Pradesh, the leading districts growing citrus are Nellore, Anantapur, Cuddapah, Prakasam, East Godavari, West Godavari, Nalgonda, Karimnagar and Guntur.

Around 823 species of different insect and mite pests were known to be associated with citrus (Ebeling, 1959). Out of these, 165 species are important in India causing an estimated loss of 30 per cent in yields (Pruthi and Mani, 1945). Many of these pests damage the crop at all stages of crop growth i.e, from nursery stage to bearing trees (Butani, 1979). About 55 species of insect and mite pests were reported feeding on citrus in Tirupati region (Ramasubba Reddy *et al.*, 1989).

Among the various pests that attack citrus, the lemon butterfly, *Papilio demoleus* Linnaeus (Lepidoptera : Papilionidae) is important because of its regular occurrence in nurseries, young plantation and on new flush of grown up trees. Outbreaks of *P. demoleus* were not uncommon as experienced in Nagpur region (Bindra, 1957). This pest occurred in epidemic form during eighties in South-zone of Andhra Pradesh also (Ramasubba Reddy, 1986). The citrus caterpillar, *P. demoleus* can feed and breed on all varieties of cultivated and wild citrus plants. It was also recorded on various species of plants belonging to family Rutaceae (Atwal, 1964). The caterpillars can feed voraciously and cause extensive damage in the larval stage particularly to nursery plants and cause great loss to seedlings and young saplings leaving behind midribs only. Severe infestation resulted in entire defoliation of the tree (Butani and Jotwani, 1975). The attack of pest retards plant growth and decreases fruit yield (Pruthi, 1969).

Although occurrence of citrus butterfly has been reported from Andhra Pradesh, comprehensive information regarding the influence of weather parameters on citrus butterfly in Tirupati region is lacking. Studies on seasonal incidence may help in planning effective management strategies as it indicates the fluctuations in pest activity revealing conducive periods for pest development as well as insect free periods during crop growth. Hence, the present studies include seasonal occurrence of citrus butterfly and natural control factors that influence the pest at field level.

Considering the severity of the pest causing extensive damage to nursery plants, young plants or bearing trees, studies were taken up to assess the influence of larval density on growth of the host plant by subjecting to different levels of larval population.

Though chemical control of insects offers quick results, indiscriminate use of insecticides lead to adverse effects, besides increasing the cost involved in plant protection. With a view to reduce the negative effects of the chemical pesticides, certain bio-pesticides were evaluated against *P. demoleus* under field and laboratory conditions.

Hence with a view to fill up the gap, the present investigation was undertaken with the following objectives.

1. Seasonal occurrence of citrus butterfly, *P. demoleus* on acid lime and sweet orange in relation to biotic and abiotic parameters of the region.
2. To study the comparative biology of citrus butterfly, *P. demoleus* on sweet orange, acid lime and curry leaf.
3. Identification of natural enemies of citrus butterfly, *P. demoleus*.
4. Influence of *P. demoleus* in relation to growth parameters of host plant.
5. Evaluation of certain bio-pesticides against citrus butterfly.

Chapter - II

Review of Literature

CHAPTER - II

REVIEW OF LITERATURE

The review of literature pertaining to the objectives of the present study on the seasonal incidence, biology, natural enemies, growth parameters and evaluation of certain bio-pesticides against citrus butterfly, *Papilio demoleus* Linn. is presented below under appropriate headings.

2.1 DISTRIBUTION, HOST RANGE AND NATURE OF DAMAGE

The citrus caterpillar, *Papilio demoleus* Linn. was reported as a serious defoliator and widely distributed throughout the citrus growing areas. Besides citrus, it was also recorded on various species of plants belonging to family Rutaceae (Fletcher, 1914 ; Ayyar, 1940 ; Jandu, 1942 ; Bindra, 1957 and Atwal, 1964).

Jandu (1942) reported a number of alternate host plants for citrus caterpillars viz., *Trichodesma indicum, Feronia elephantum, Glycosmis pentaphylla, Zizyphus jujuba, Ruta graveolens, Citrus decimana, Chloroxylon sweitenia, Psoralea corylifolia, Murraya koenigii* and *Aegle marmelos* were the most preferable food plants for this pest.

Sontakay (1943) reported serious out break of *Papilio demoleus* in Madhya Pradesh during July, 1940 and again in the year 1943 in which, caterpillars defoliated the entire orchards of Nagpur, and also caused flower and fruit drop from tender twigs. During the out break, more than 1000 caterpillars per tree were noticed and plants like bael (*Aegle marmelos*), bawachi (*Psoralea corylifolia*) and curry leaf plant (*Murraya koenigii*) were also heavily infested.

Atwal (1964) reported that the genus *Papilio* was widely distributed all over the world. *Papilio demoleus* was found in Africa, greater parts of Asia, Formosa and Japan. It has been reported as a pest throughout India but not in the U.S.A, Canada, Europe and the U.S.S.R. He reported that young larvae fed only on fresh leaves and terminal shoots. They fed from the margin inwards reaching the midribs and in later stages, larvae fed even on mature leaves. The pest was particularly devastating in the nurseries and in cases of severe damage, the entire plant may be defoliated.

Purohit *et al.,* (1966) recorded a weed, *Psoralea corylifolia* as an alternate host plant of the lemon butterfly, *Papilio demoleus* L.

Basu *et al.,* (1969) reported that the pest was particularly serious in nursery plants and caused a great loss to seedlings and young saplings in Darjeeling district, West Bengal.

Thakare and Borle (1969) stated that the caterpillars of *P. demoleus* also damaged bael (*Aegle marmelos*), kadhu limb (*Murraya koenigii*), bawachi (*Psoralea corylifolia*) and bhira (*Chloroxylon sweitenia*) and further reported that the pest caused 100 per cent defoliation in Maharashtra.

Butani (1973) reported that the pest (*P. demoleus*) was widely distributed from Formosa to Arabia including Burma, Bangladesh, Ceylon, India and Pakistan. The pest attacked almost all citrus varieties but the preferred host being Malta (*Citrus sinensis* Osbeck). Its incidence was also recorded on ber (*Zizyphus jujuba* Lamk.).

Butani and Jotwani (1975) reported that severe infestation of *P. demoleus* resulted in total defoliation of the infested tree.

Resham *et al.*, (1986) reported that the caterpillars were voracious feeders and defoliated the entire seedlings or young trees in no time. Damage resulted in death of the seedlings whereas young trees suffered to a greater extent with retarded growth.

2.2 SEASONAL ABUNDANCE

Sontakay (1943) recorded breeding of *Papilio demoleus* L. throughout the year in Vidharbha region of Maharashtra.

Hayes (1957) reported that citrus caterpillar passes through three to four generations in a year. In the plains, it was found throughout the year. Where winter temperature was very low, it hibernated in the pupal stage. The butterflies emerged from the hibernating pupae in the month of March and gave rise to larvae towards the end of April. The population got a setback due to intense heat in June. However, there was fresh egg laying in July and the population increased in August. He reported the maximum pest activity in the month of September. Since there was overlapping of generations, all stages of the pest were found throughout the year, except in winter when only pupae were found.

Ganguli and Ghosh (1967) reported that the occurrence of butterflies was noticed in the months of February, April, June, August and November.

Bindra (1969) and Nair (1975) observed the peak population in the months of April and July - October.

Ramasubba Reddy (1984) recorded more number of caterpillars of *P. demoleus* during January - February and the population declined during hot summer months and again increase of population was noticed during June and July, then the population declined during winter months.

Resham *et al.*, (1986) reported that the pest was found throughout the year but rare in winter months with four to five overlapping generations in a year.

Maheswarababu (1988) reported that the population of *P. demoleus* was present in June - July and reached to its maximum in the months of August and September, from October onwards the pest population declined and there was no population from second fortnight of November to the end of December.

Yadav and Rizvis (1995) reported that the lemon butterfly, *Papilio demoleus* was active during February - June months at Faizabad, Uttar Pradesh.

2.3 BIOLOGY AND MORPHOMETRICS

Atwal (1964) reported that *P. demoleus* can feed and breed on all varieties of cultivated and wild citrus. Eggs hatched in 3-7 days and egg stage lasted for 2.7 days in June, 4 days during March - April and 5 days during October - November months. The duration of the larval life was completed in 15.9 days in March, 11.3 days in April and 8.5 days in May - June months. But under low temperature conditions the larval developmental period was more i.e 28.6 days in November and 28.8 days in December.

Larva spins a girdle around its body in 45 minutes and pupated with in 16 hours in summer and 38 hours in winter. The duration of the pupal period was recorded as 8.5 days in summer, 9-11 days in spring and autumn and extremely long duration of 143 days in winter. He also reported, pre-copulation period (5-25 hours), copulation period (1.5 hours), oviposition period (2-5 days), fecundity (75-120 eggs / female) and adult longevity in males (3-4 days) and females (7 days).

According to Atwal (1964) the diameter of the egg was 1.04 mm, full grown larva measured 40 mm in length and 6.5 mm in width. The length and width of pupae were 29.5 and 9.3 mm respectively and the adult butterflies measuring 29 mm in body length and wing expansion of 94 mm.

Misra and Pandey (1965) reported the egg, larval, prepupal and pupal stages of *P. demoleus* L. ranged from 3-6, 13-26, 2-3 and 7-24 days respectively with 5-6 overlapping generations in a year with fecundity of 40-183 eggs.

Ganguli and Ghosh (1967) recorded five broods of *P. demoleus* per year and *Citrus reticulata* was found to be more preferred host by this pest. According to him, the eggs were globular, creamy yellow when freshly laid with 1.1 mm diameter, but before hatching the colour turned to greyish with

reddish brown streaks all over the chorion and the egg period was 3-4 days. The length and breadth of newly hatched, second, third, fourth and fifth instar larvae were 2.5 and 0.5 mm, 7.0 and 2.0 mm, 10.0 and 3.0 mm, 14.0 and 4 mm and 30.0 and 6.0 mm. Pupa measured 1.5 cm in length and 1.0 cm width. The duration of larval instars were found to be 2-3, 2-3, 2-4, 3-4 and 3-5 days in first, second, third, fourth and fifth instars respectively. The total larval duration varied from 13-18 days and pupal period from 8-10 days.

Pandey and Bogawat (1969) studied the growth and development of *P. demoleus* L. on *Psoralea corylifolia* and lemon (*Citrus medica*). They reported that the larval and pupal durations were 17.0 and 7.5 days and 14.63 and 7.5 days on *P. corylifolia* and lemon respectively. Percentage survival of the larvae varied from 32.5 per cent in *P. corylifolia* to 62.5 per cent on lemon. The development of *P. demoleus* was completed in 24.5 and 22.13 days on *P. corylifolia* and lemon respectively.

Sharifi and Zarea (1970) recorded the durations of 3.24, 18.24 and 11.7 days for egg, larval and pupal stages respectively and the butterfly had four generations in a year with life cycle of 33.19 days. The overall duration of the larval stage was statistically shortest on lemon and longest on mandarin orange.

Yunus and Munir (1972) reported that the average duration of larval period was least on certain varieties of citrus viz., sour orange (12.5 days), lemon (12.8 days), shaddock (13.2 days) and sweet orange (13.4 days).

Butani (1973) recorded egg, larval and pupal periods of *P.demoleus* L. as 3, 11 and 7 days during summer and 8, 28-30 and 56-98 days during winter respectively and observed hibernation in pupal stage.

Atwal (1977) reported that the duration of fourth instar larva lasted 138.3, 19.5 and 88.8 hours, prepupal stage was 22.5, 15.25 and 14.4 hours and the pupal stage was 246, 204 and 176.8 hours at temperatures 25°C, 30°C and 35°C respectively.

Burger (1978) reported that the secretions produced by osmeterium of the fifth instar larvae of *P. demoleus* L. caterpillars contained iso-butyric acid, 2-methyl butyric acid and small quantities of methyl and ethyl esters of these acids.

Madansuri *et al.,* (1979) recorded the mean head capsule width of first, second, third, fourth and fifth instars of *P. demoleus* as 0.61, 0.95, 1.49, 2.33 and 3.64 mm respectively.

Srivastava and Kumar (1979) observed that the female larva had a pair of small triangular areas of transparent cuticle on each of the eighth and ninth sternites and the pupa with a small narrow vertical furrow extending over these two sternites. The male larva and pupa could be distinguished only by absence of these characters.

Badawi (1981) reported that the minimum and maximum periods for egg, larval and pupal stages of *P. demoleus* lasted for 3.1 and 6.1, 12.9 and 22.7 and 8.0 and 22.4 days respectively and it had eight generations in a year in Saudi Arabia.

Westwood (1985) described different species of *Papilio* viz., *Papilio empedocleus, Papilio deiphobus, Papilio lacedemon, Papilio idaeus, Papilio astyanax*, *Papilio polymnestor* and *Papilio ulysses*.

Resham *et al.*, (1986) reported that the incubation, larval and pupal periods were 3-7, 10-40 and 8-36 days respectively and could complete its life cycle in 22-42 days in summer and more than 100 days in mid winter with 4-5 overlapping generations per year. The sizes of egg, full grown larva, pupa and adult wing expansion were also recorded as 1.0-1.5 mm, 28-35 mm, 25-35 mm and 80-100 mm respectively. Oviposition period ranged from 2-5 days with fecundity of 75-120 eggs per female.

Gupta and Mishra (1988) reported that the duration of various developmental stages of *Papilio machaon asiatica* on fennel (*Foeniculum vulgare*) was negatively related to temperature. They also recorded that larval duration was short and highest percentage of pupation on fennel, followed by foliage of carrots and lemons. *Coriandrum sativum* was unsuitable for larval development.

Maheswarababu (1988) recorded that the diameter of egg was 1.04 mm. The length and width of first, second, third, fourth and fifth instars were 6.85 and 1.9 mm, 10.5 and 3.0 mm, 14.5 and 4.0 mm, 29.5 and 6.0 mm and 42.0 and 6.50 mm respectively on Sathgudi. According to him, total larval period was 8.96 days and the developmental period from egg to adult was 21.03 days.

Maheswarababu (1988) recorded that the percentage survival was maximum on Sathgudi with 96.00, 98.33, 98.3, 99.13 and 100 per cent and a minimum of 62.4, 85.89, 91.04, 96.72 and 91.55 on curry leaf in first, second, third, fourth and fifth instars respectively.

Radke and Kandalkar (1988) reported that mating period, pre-oviposition and ovipositional periods of *P. demoleus* as 1.5-2 hours, 1 day and 2 days respectively. The larval, pre-pupal and pupal periods lasted for

15-22 days, 20-24 hours and 8-12 days respectively, with 15-22 eggs per female.

Maheswarababu (1988) studied the comparative biology of *P. demoleus* on four host plants viz., Sathgudi, Rangpur lime, Jambiri and curry leaf and reported the total developmental period from egg to adult was shortest (21.03 days) on Sathgudi and longest (28.69 days) on curry leaf. It took 21.56 days on Rangpur lime and 22.66 days on Jambiri.

Feeny *et al.,* (1989) reported that females of *Papilio polyxenes* laid more eggs on plants treated with contact stimulants and volatiles from carrot leaves than treated only with contact stimulants. Because volatiles enhanced landing rates and females alighted more frequently on artificial leaves treated with host volatiles.

Radke and Kandalkar (1989) reported that a single female of *Papilio demoleus* laid 15-22 eggs with mean incubation period of 5 days. The total larval period was completed in 18 days.

Singh and Gangwar (1989) reported that the mean durations of egg stage, first - fifth larval instars of *Papilio demoleus* on khasi mandarins were 4.7, 5.3, 5.1, 4.2, 4.2 and 3.5 days. Pupal duration lasted for 19.1 days and

the life span of male and female adult butterflies were 5.1 and 5.8 days respectively.

Leslie and Berenbaum (1990) reported that osmeterial glands present in 3rd and 5th instar larvae of swallowtails showed defensive function against predators.

Jalali *et al.*, (1991) reported the occurrence of paired bursa copulatrix and paired spermathecae with all their components duplicated on two sides in an adult female of *Papilio demoleus*, led to the abnormal development of female reproductive organs.

Watanabe (1992) reported that females fed with 10 per cent sugar solution maintained weight for 15 days after emergence, and those given with 20 and 50 per cent gained 20 and 60 per cent weights respectively. He also stated that female butterflies which were given greater than 10 per cent sugar solution produced more mature eggs.

Arikawa (1996) reported that males of *Papilio xuthus* use genital photoreceptors to locate the female's genitalia and light plays an important role in butterfly mating.

Asokan (1997) reported that females of *Papilio demoleus* laid an average of 12 eggs / day on acid lime (*Citrus aurantifolia* Swingle) and adult longevity was 4-5 days. The total life cycle took 30-50 days with an additional instar (6^{th}).

Ramana *et al.*, (1997) reported that the colouration of the pupa of *Papilio polytes* was green as against the normal brown colour.

Tripathi *et al.*, (1998) reported the comparative biology of *Papilio demoleus* on lemon (*Citrus limon*) and babchi (*Psoralea corylifolia*). Larval and pupal periods and also total life cycle were longer on babchi than on lemon. Larvae consumed more lemon leaves than babchi but females showed more preference to babchi for egg laying compared to lemon.

Watanabe and Hirota (1999) reported that there was a positive correlation between adult male sugar intake and spermatophore mass at the time of mating. A single male must ingest 390 mg of 20 per cent sucrose solution.

2.4 NATURAL ENEMIES OF CITRUS BUTTERFLY, *P. demoleus*

Atwal (1964) reported that young caterpillars of *P. demoleus* were attacked by yellow wasp (*Polistes hebreus* F.), preying mantis (*Creobrator*

gemmatus Soll.) and spiders. The pupae were parasitised by the *Pteromalus* species and the eggs by another minute hymenopterous parasite.

Yeshbir Singh (1967) recorded two hymenopterous parasites *Charcops* sp. and *Brachymeria* sp. on larvae of *Papilio demoleus* Linn.

Ramzan and Darshan Singh (1979) recorded 124 pupae of *Pteromalus puparum* from a single pupa of *P. demoleus*.

Balraj Singh and Anand (1982) reported that high temperature (35°C) and low relative humidity (60%) acted as limiting factors in the development and survival of the parasite. A combination of 30°C and 60-75 per cent relative humidity were found optimum for the development, survival and parasitising efficiency of *Apanteles flavipes* in parasitising *Chilo partellus* (Swinhoe).

Narayanan and Gopalakrishnan (1984) reported that cytoplasmic polyhedrosis virus caused death of *Papilio demoleus* larvae in 9-16 days. The dead larvae infected with CPV were bent backwards dorsally. They also observed that the CPV infection was associated with natural parasitisation by the internal, gregarious parasite *Apanteles papilionis* Viereck.

Krishnamoorthy and Singh (1986) reported two species of egg parasitoids viz., *Trichogramma chilonis* and a scelionid, *Telenomus* sp. on *Papilio demoleus* and *Papilio polytes.* They reported that *T. chilonis* parasitised 1-2 day old eggs of *Papilio* sp. and the rate of parasitism was as high as 75.9 per cent. They also suggested that *T. chilonis* could be mass reared on eggs of pyralid *Corcyra cephalonica* and released to suppress populations of *P. demoleus* and *P. polytes.*

Resham *et al.,* (1986) reported *Apanteles lunatus* and *Pteromalus puparum* as natural enemies of *P. demoleus* in Nepal citrus orchards.

Krishnamoorthy (1987) reported that the female *Apanteles papilionis* Viereck. exhibited an arrhenotokous reproduction and preferred the first four larval instars of *Papilio demoleus* L. for parasitisation. The larval development of the parasite was influenced by the various larval instars of the host and the duration of parasitic development decreased with increase in host age (instar) at the time of parasitisation.

Krishnamoorthy and Singh (1988) recorded two egg parasitoids, *Trichogramma chilonis* and *Telenomus* sp, two hyper parasitoids of *Ooencyrtus papilionis* and one larval parasitoid, *Apanteles papilionis* on citrus pests *Papilio demoleus* and *P. polytes.* Percentage parasitism by *T. chilonis,*

Telenomus sp. and *O. Papilionis* was 0-65, 10-78 and 1-73 per cent respectively.

Krishnamoorthy and Singh (1988) stated that the extent of parasitisation of *Papilio demoleus* L. by *Apanteles papilionis* ranged upto 73.0 per cent. They observed positive correlation between *A. papilionis* and total rainfall (r = 0.370), relative humidity (r = 0.386) and minimum temperature (r = 0.377) and negative correlation with maximum temperature (r = -0.060).

Maheswarababu (1988) reported two parasites viz., *Apanteles papilionis* Viereck, a larval parasite and *Pteromalus puparum*, a pupal parasite on *Papilio demoleus*.

Jalali and Singh (1990) recorded a new hymenopteran parasitoid *Ooencyrtus papilionis* in addition to *Telenomus* sp. and *Trichogramma* sp. on eggs of *Papilio demoleus*. A single egg produced 3-7 adults of *O. papilionis*, which lived for 5 days.

Singh (1991) reported the following natural enemies viz., *Apanteles papilionis, Holcojoppa coelopyga, Melalophacharops* sp, *Brachymeria jambolana* and *Pteromalus puparum* on four species of *Papilio* viz., *P. demoleus, P. polytes, P. polymnestor*, and *P. helenus*.

Balagangadhar Tilak (1992) studied the effect of natural parasitisation on *Papilio demoleus* Linn. by the braconid larval parasite *Apanteles papilionis* Viereck. revealed that there was no parasitisation in the month of May, 1991 and during January-March, 1992. The parasitisation increased with increase in rainfall and relative humidity and decreased with increase in mean maximum and minimum temperatures.

Garraway and Bailey (1992) recorded the egg mortality of 87.4 per cent due to the genus *Ooencyrtus* in the population of *P. homerus* in Jamaica during July - October.

Zitani *et al.*, (1997) reported a gregarious endoparsitoid of papilionid larvae *Meteorus papiliovorus* from Costarica in addition to *P. anchisiades idaeus* on citrus.

Singh and Singh (1998) reported the coccinellids *Coccinella septempunctata, Chilomenes sexmaculata, Anegleis cardoni* and *Brumoides suturalis*, the salticid, *Carrhotus* sp, the vespid *Vespa orientalis* and an unidentified species of preying mantis preying on different species of insect pests. Coccinellids, vespid and the preying mantis for the first time reported as predators of the lemon shoot butterfly and citrus butterfly, *Papilio demoleus*.

2.5 GROWTH PARAMETERS

Atwal (1964) reported that a full grown larva of *Papilio demoleus* Linn. consumed at the rate of two square inches per day, consuming 20 square inches in its entire life.

2.6 EFFICACY OF INSECTICIDES

Sharma and Srivastava (1970) reported that 0.2 per cent carbaryl was the most effective treatment among different insecticides tested, when the treated foliage of *Citrus reticulata* was subjected to artificial infestation of *P. demoleus* caterpillars.

Resham *et al.*, (1986) reported that *Bacillus thuringiensis* Berliner was highly effective in the control of citrus butterfly, *Papilio demoleus* in Nepal.

Solunke and Deshpande (1991) stated that five plant extracts i.e, pimpal (*Ficus religiosa*), beshram (*Manchoria hastaefolia*), parthenium (*Parthenium hysterophorus*), neem (*Azadirachta indica* A.) and datura (*Datura stramoneum*) significantly reduced the pest population of *Papilio demoleus.* Permethrin produced best results with mean mortality of 85.4 per cent followed by *P. hysterophorus* extract (52.8%).

Balagangadhar Tilak (1992) reported that among the plant products, allitin (1.0%) gave highest per cent reduction over control (94.56%) followed by repelin (81.05%), margosol (80.13%), neem guard (78.25%), necknool (77.05%), vepanic (76.71%), karrich (65.07%), annmet (63.77%), sitpal (60.96%) and wellgro (21.16%) at 1.0 per cent.

Jhonson *et al.,* (1995) reported that *Bacillus thuringiensis* applied at a rate of 40 BIU / ha was found toxic to early and later (4^{th}) instar larvae of *Papilio glaucus, P. canadensis* and *Callosamia primethea.* Toxicity to early instar of *P. glaucus* persisted upto 30 days. The results of these studies indicated that *B. thuringiensis* sprays were also toxic to some non-target lepidopterans for atleast 30 days after the spray.

Ranjeet Singh *et al.,* (1996) reported that spraying of an aqueous extract of neem seed kernel at 0.5 per cent twice with an interval of 8 days was effective in providing protection against *Papilio demoleus.* Although low mortality (23.3%) was reported, the extract had strong antifeedant and repellent effects and was effective as a moulting inhibitor.

Chauke *et al.,* (1999) reported that among the plant products azadirachtin (0.3%) was found significantly superior over neem seed kernel extract (5%) and NLE (Neem leaf extract) 5 per cent against the lemon butterfly (*Papilio demoleus* L.).

Shivankar (1999) reported Dipel (*Bacillus thuringiensis* Berl.) spray at the rate of 0.05 per cent was highly effective against lemon butterfly and entamopathogens like bacterium, *Serratia marcescens* and fungus, *Fusarium* sp. also kill the lemon butterfly substantially.

Venkadasubramanian and David (1999) reported that *Bacillus thuringiensis* Var. *Kurstaki, Bacillus thuringiensis* Var. *galleriae* and B.t. var. *Kurstaki* + *aizawai* (each at 0.1%) in combination with botanicals viz., neem seed oil (*Azadirachta indica* A.) (1.5%), Palmarosa plant oil (*Cymbopogan martini* Wats.) (0.5%) proved significantly superior against tobacco cutworm, *Spodoptera litura* (Fabricius) and gram podborer, *Helicoverpa armigera* (Hubner).

Chapter - III

Materials and Methods

CHAPTER - III

MATERIALS AND METHODS

Present studies were carried out in Citrus Improvement Project where "All India Co-ordinated Research Project (AICRP) on Tropical Fruits (Citrus)" is functioning. The studies were conducted during July, 2000 - June, 2001. The materials used and the methods employed in these investigations are presented below.

3.1 SEASONAL OCCURRENCE OF CITRUS BUTTERFLY, *Papilio demoleus* Linn. ON SWEET ORANGE AND ACID LIME

Studies were carried out on Sathgudi sweet orange and Tenali acidlime plants grown at AICRP on Tropical Fruits (Citrus), Tirupati from July, 2000 to June, 2001. Observations were recorded on ten unprotected trees of ten years old each of acid lime and sweet orange to know the population fluctuations during the period of study in relation to climatic variations. From each tree, observations on larval population of citrus butterfly were taken at fortnightly interval. Sampling was done on five randomly selected tender twigs of 10-15 cm length covering the four sides. These studies also provide information about the favourable periods for pest build up that help in the management of the pest.

The weather parameters viz., maximum and minimum temperatures, relative humidity and rainfall were recorded continuously during the period of study. The data was correlated with the population of citrus butterfly, *P. demoleus*.

3.2 BIOLOGY AND MORPHOMETRICS

Comparative biology of citrus butterfly was studied during November and December of 2000 in the insectary of Entomology Department on Tenali acid lime (*Citrus aurantifolia* Swingle), Sathgudi sweet orange (*Citrus cinensis* Osbeck) and curry leaf (*Murraya koenigii* Linn.).

3.2.1 Mass culture

Fifth instar larvae of *P. demoleus* were collected from infested plants of citrus improvement project, Tirupati. Larvae were kept in glass troughs and were fed with fresh sweet orange leaves till pupation. After adult emergence, they were released into cages of 60 x 30 cm size and were fed with cotton swabs wetted in ten per cent sugar solution that were hanged down in the cages. Fresh tender twigs of acid lime, sweet orange and curry leaf were placed in conical flasks containing water and the flasks with twigs were kept in cages for egg laying. The twigs were changed daily and the eggs laid were kept separately for incubation. After hatching the larvae were maintained on natural hosts by regularly replenishing new leaves. Biology of *P. demoleus*

was documented under laboratory conditions on three hosts viz., sweet orange, acid lime and curry leaf. Newly hatched caterpillars were transferred to separate petridishes individually containing the tender leaves of the host material. A moistened filter paper was kept in each petriplate to prevent the drying of leaves. The caterpillars were maintained in petridishes upto third instar. Later on they were transferred and reared in glass troughs and allowed them to complete first generation. Hygienic conditions were maintained during the rearing period for the normal growth and development of the larvae. Food material was changed every day and the following observations were recorded during the studies.

3.2.2 Observations on Egg

Incubation period of the egg was recorded on three hosts. The eggs were measured with the help of an occular micrometer. A sample size of 10/15 was involved for this purpose.

3.2.3 Observations on larvae

Morphometric data with regard to body length, width and head capsule width and durations of different instars was recorded on all hosts. Body length, width and width of head capsule of first instar larvae were measured with the help of an occular micrometer. From second instar onwards the morphometric data was recorded using a standard graph paper method.

3.2.4 Pupal observations

The length and width of pre-pupa and pupa were recorded using a standard graph paper method. The durations of pre-pupal and pupal stages on all three hosts were also recorded.

3.2.5 Adult butterfly observations

Fecundity studies were made by releasing freshly emerged five paired adults on each host, kept separately in cages provided with young twigs of the respective host.

Observations regarding pre-copulation, copulation, pre-oviposition, oviposition and post-oviposition periods for females and adult longevity, body length, width, wing expanse and sex-ratio for both males and females were also recorded during biology studies.

3.3 NATURAL ENEMIES OF *P. demoleus*

While taking observations on seasonal occurrence of *P. demoleus,* larvae were collected from the field at every fortnightly interval and maintained in the laboratory to know the natural enemy occurrence and also per cent parasitisation. A sample size of (50) larvae were involved for this study. The emerged larval parasitoids were collected and preserved through standard methods and were sent to Zoological Survey of India, Kolkata for identification.

3.4 INFLUENCE OF *Papilio* LARVAL FEEDING ON GROWTH PARAMETERS OF THE SATHGUDI HOST PLANT

Studies were carried out on two year old Sathgudi sweet orange plants grown at AICRP on Tropical Fruits (Citrus), Tirupati during January - February, 2001. Six plants of uniform height and canopy were selected and excess branches and unhealthy leaves were removed. To prevent cross infestation from other pests of citrus, each plant was protected with a net of 1 x 1/2 m size (Plate 1). Second instar larvae reared in the laboratory were transferred to these netted plants at the rate of 1, 2, 3, 4 and 5 larvae for five plants and sixth plant was kept as check which is free from larval infestation. The impact of larval feeding on plant growth was studied by considering plant height, total number of leaves, total number of branches, number of damaged leaves and damaged leaf area by visual observation at five days interval. Final observation was recorded before the end of the larval period. These treatments were replicated four times to draw relevant inferences. Mean per cent leaf damage and per cent leaf area damage were worked out in each observation and the data was analysed statistically and results are presented.

3.5 EVALUATION OF CERTAIN BIO-PESTICIDES AGAINST CITRUS BUTTERFLY, *P. demoleus*

Two experiments were conducted separately to evaluate the efficacy of bio-pesticides against larvae of *P. demoleus* under field and laboratory conditions.

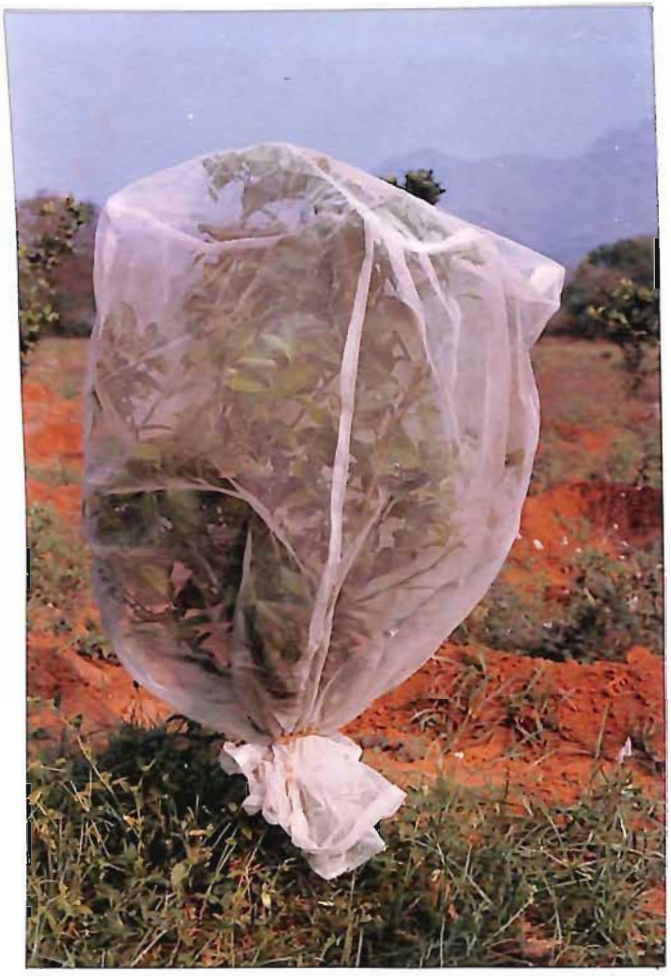


Plate 1. **Sweet orange plant protected with net**

3.5.1 Field experiment

To evaluate the efficacy of different bio-pesticides against citrus butterfly, *P. demoleus*, a field experiment was conducted at citrus improvement project, on one and half years old Sathgudi sweet orange nursery plants during second fortnight of December, 2000. Spraying was done with five promising bio-pesticides including one bacterial insecticide tested in three different dosages and one fungal insecticide. Remaining three were neem formulations. The formulation, concentration, dosage, trade name, common name and source of supply of the insecticides involved in this study are furnished in the Table 1.

Each treatment was replicated thrice in a randomised block design in a plot size of 2 x 6 m for each treatment. An untreated check in each block was maintained for comparative studies. Each treatment was sprayed with three litres of spray solution. High volume spray fluid type, knap-sack sprayer was used for imposing the treatments.

3.5.1.1 Preparation of insecticidal solution

The quantity of the chemical required was calculated as per the formula given below.

$$V_1 = \frac{V_2 S_2}{S_1}$$

Table 1 : Details of the bio-pesticides used in the experiment

S. No.	Common name	Concen-tration (%)	Dose	Trade name	Chemical / Scientific name	Formulation	Source of Supply
1.	Bacterial insecticide	0.0025 (2.09×10^7)	0.5 g/lit	Halt	*Bacillus thuringiensis* Var. *Kurstaki*	5% WP	Wockhardt Limited, Mumbai
2.	Bacterial insecticide	0.005 (4.23×10^7)	1 g/lit	Halt	*Bacillus thuringiensis* Var. *Kurstaki*	5% WP	Wockhardt Limited, Mumbai
3.	Bacterial insecticide	0.0075 (6.19×10^7)	1.5 g/lit	Halt	*Bacillus thuringiensis* Var. *Kurstaki*	5% WP	Wockhardt Limited, Mumbai
4.	Fungal insecticide	— (5.05×10^7)	1 g/lit	-	*Beauveria bassiana*	—	Basarass Biocon (India) Pvt. Ltd., Chennai
5.	Neem oil	0.5	5 ml/lit	Neem oil	*Azadirachta indica*	100% EC	Locally purchased
6.	Neem seed kernel extract	5	50 g/lit	-	*Azadirachta indica*	—	Prepared in the laboratory
7.	Azadirachtin	0.005	5 ml/lit	Neemazal	*Azadirachta indica*	1% EC	EID Parry India Limited, Dare house, Chennai - 1

where,

V_1 = Volume of the concentrated spray material

S_1 = Strength of the concentrated spray material

V_2 = Volume of the diluted spray material

S_2 = Strength of the diluted spray material

Care is taken for proper mixing of the insecticide with water.

3.5.1.2 Recording of data

Larval population was recorded one day before spraying and on 1, 3, 5, 7 and 10 days after spraying as post treatment counts. The per cent population reduction over control was calculated and transformed into angular values and analysed statistically and the results are interpreted on the basis of the scrutiny.

3.5.1.3 Statistical analysis

The mean per cent population reduction over untreated check was calculated for all the treatments by using the following formula.

$$\text{Per cent population reduction} = \frac{\text{Population in untreated check} - \text{Population in treatment}}{\text{Population in untreated check}} \times 100$$

The percentages thus obtained were transformed into angular values and analysed statistically. The data was analysed by Fisher's analysis of variance in Randomised Block Design. Significance of different treatments was tested by 'F' test at 5 per cent and 1 per cent levels of probability. The critical difference worked out for significant treatments, was utilised for comparing the treatmental means.

3.5.2 Laboratory Experiment

Laboratory experiment was conducted with six treatments consisting of one bacterial insecticide tested in three different dosages, one fungal insecticide, one neem formulation and one untreated check for comparison.

The experiment was conducted with fixed number of (10) uniformly sized third instar larvae of *P. demoleus* reared on fresh sweet orange leaves. The insecticidal solution was prepared in the same manner as in field experiment. Each treatment was replicated four times in a randomised block design. Bacterial and fungal insecticides were given by leaf dip method and from second day onwards the larvae were given normal feed and for neem formulation the spray solution was sprayed on a sweet orange plant in Citrus improvement project and the same feed was provided regularly.

3.5.2.1 Recording of data

Observations on the effects of treatment in terms of death or moribund stage were recorded daily till 100 per cent mortality was observed in all treatments. Per cent cumulative mortality values were calculated and transformed into angular values and analysed statistically and the results are presented.

Chapter - IV

Results

CHAPTER - IV

RESULTS

4.1 SEASONAL ABUNDANCE OF CITRUS BUTTERFLY, *Papilio demoleus* Linn. ON SWEET ORANGE AND ACID LIME

Studies on the seasonal abundance of citrus butterfly, *P. demoleus* on Sathgudi sweet orange and Tenali acid lime were carried out during July, 2000 to June, 2001 to know about the population fluctuations and also to understand the favourable periods of pest build up, so as to synchronise the management strategies of the pest.

4.1.1 Seasonal abundance of citrus butterfly on Sathgudi sweet orange

The data regarding larval population of citrus butterfly, temperatures (both maximum and minimum), relative humidity and rainfall are presented in Table 2. There was no infestation of citrus butterfly in July and first fortnight of August, 2000 and during second fortnight of March to June, 2001. Even though there was new foliage during April and May months, citrus butterfly infestation was not noticed. The citrus butterfly infestation initiated from second fortnight of August, 2000 with a population of 25.80 larvae per 50 twigs. Thereafter, butterfly population increased gradually recording high population during second fortnight of September (145.60). Pest reached to its peak activity during October, November and December, 2000

Table 2 : Seasonal abundance of citrus butterfly, *Papilio demoleus* Linn. on sweet orange and acid lime during July, 2000 to June, 2001

S. No.	Period of observation	Number of caterpillars / 50 twigs		Mean max temp. (°C)	Mean min temp. (°C)	Relative humidity (%)	Rainfall (mm)
		Sweet orange	Acid lime				
1.	**July, 2000**						
	I fortnight II fortnight	— —	— —	32.15 36.35	24.90 25.50	56.50 44.75	007.65 000.00
2.	**August**						
	I fortnight II fortnight	— 25.80	— —	33.95 32.20	24.05 24.50	61.50 60.00	062.45 017.53
3.	**September**						
	I fortnight II fortnight	88.50 145.60	18.5 40.2	34.15 32.60	24.45 23.60	54.50 71.25	005.45 077.25
4.	**October**						
	I fortnight II fortnight	162.50 160.40	98.7 135.6	30.90 32.25	22.70 21.20	76.00 62.75	086.25 008.50
5.	**November**						
	I fortnight II fortnight	175.30 180.70	150.50 168.90	31.13 29.00	19.73 20.15	62.67 72.50	009.90 045.00
6.	**December**						
	I fortnight II fortnight	185.70 175.20	170.20 162.60	27.90 27.55	16.35 17.35	70.00 67.75	024.70 023.60
7.	**January, 2001**						
	I fortnight II fortnight	140.20 115.50	152.70 158.90	28.65 29.20	18.15 15.75	70.50 64.75	000.00 000.00
8.	**February**						
	I fortnight II fortnight	92.80 50.28	100.89 54.52	32.50 35.90	17.26 20.50	58.83 50.25	000.0 000.0
9.	**March**						
	I fortnight II fortnight	20.02	32.27 18.56	35.50 38.10	21.00 25.25	48.25 50.50	000.0 000.0
10.	**April**						
	I fortnight II fortnight	— —	— —	35.75 36.70	23.80 24.25	52.50 53.00	027.20 080.60
11.	**May**						
	I fortnight II fortnight	— —	— —	40.55 39.70	27.40 27.85	42.75 40.75	000.0 012.0
12.	**June**						
	I fortnight II fortnight	— —	— —	36.40 37.45	26.73 28.00	49.83 44.00	005.83 007.20

recording highest number of 162.50, 160.40, 175.3, 180.7, 185.7 and 175.2 larvae per 50 twigs in both first and second fortnights respectively. Peak period of infestation coincided with the emergence of new flush.

Pest activity continued in January, 2001 with a larval population of 140.2 and 115.5 in first and second fortnights respectively. Thereafter, pest activity decreased slowly from first fortnight of February with 92.8 larvae per 50 twigs and least incidence was observed during first fortnight of March recording 20.02 larvae per 50 twigs.

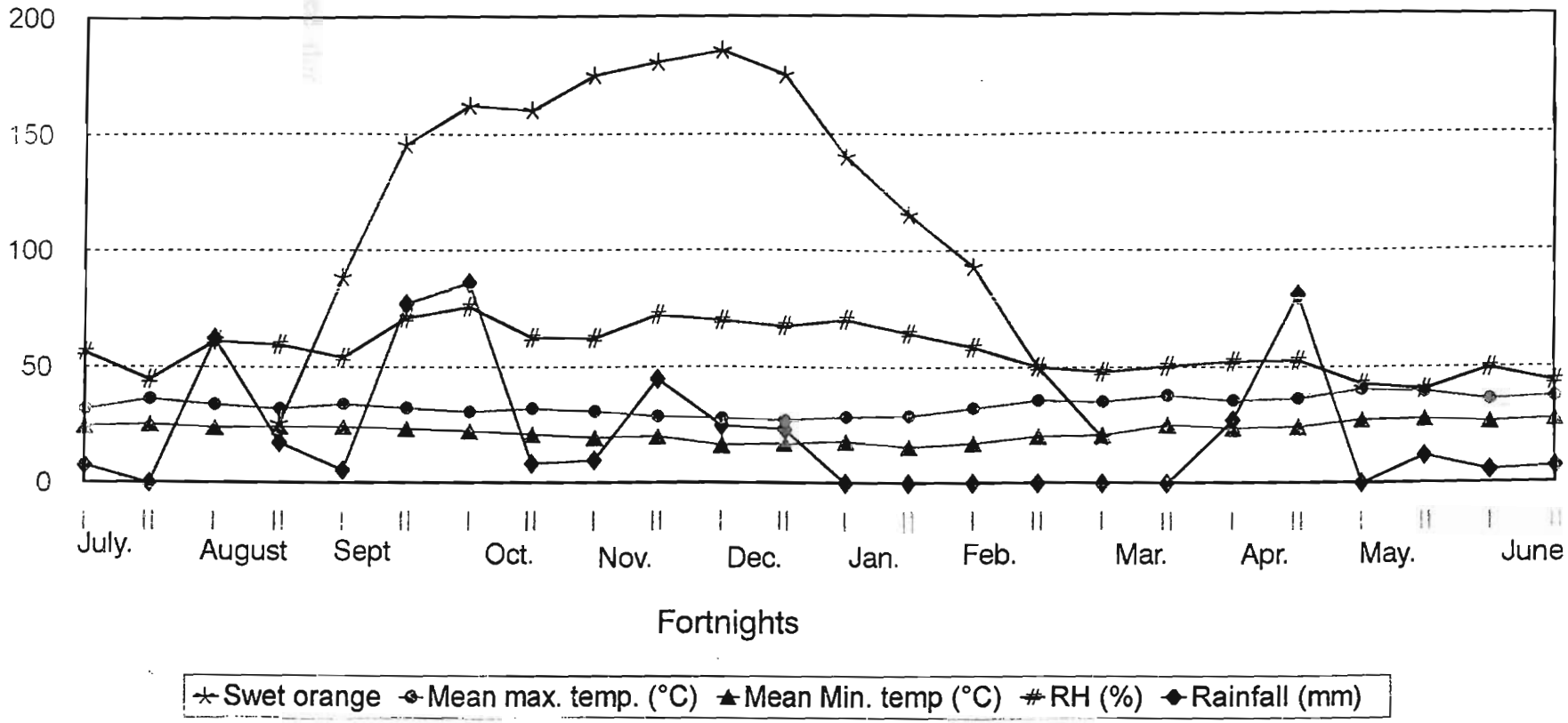
Correlation and regression co-efficients between insect population and climatic factors viz., maximum and minimum temperatures, relative humidity and rainfall were worked out (Table 3). There was a significant negative relationship between the population of *P. demoleus* and maximum temperature (r = -0.8019) and minimum temperature (r = -0.7472). However, the correlation of butterfly population with relative humidity (r = 0.8429) was positive and highly significant while the relationship between correlation of butterfly population with rainfall (r = 0.1931) was positive and non-significant.

Table 3 : Relationship between *Papilio demoleus* L. larval population on sweet orange and weather factors

Sl. No	Particulars	Correlation co-efficient	Partial regression co-efficient	't' values
1	Mean larval population and maximum temperature	-0.8019**	0.4675	0.644^{NS}
2	Mean larval population and minimum temperature	-0.7472**	-5.3151	1.370^{NS}
3	Mean larval population and relative humidity	0.8429**	7.2659	2.730**
4	Mean larval population and rainfall	0.1931^{NS}	-0.6487	1.420^{NS}

** Significant at 1% probability
NS Non-significant

Fig 1 : Seasonal abundance of Citrus butterfly, *Papilio demoleus* Linn. on Sathgudi sweet orange during July, 2000 to June, 2001



4.1.2 Seasonal abundance of citrus butterfly on Tenali acid lime

The data regarding insect population, temperatures (both maximum and minimum), relative humidity and rainfall are presented in Table 2. There was no infestation of citrus butterfly in July and August, 2000 and during April - June, 2001. Even though there was new foliage during April and May, citrus butterfly infestation was not noticed. The butterfly infestation was found initiated from first fortnight of September, 2000 with a population of 18.50 larvae per 50 twigs. Thereafter the butterfly population increased gradually from first fortnight of October recording 98.7 larvae and 135.6 larvae during second fortnight. Pest activity reached its peak during November and December months by recording the highest number of 150.5, 168.9, 170.2 and 162.6 larvae per 50 twigs in first and second fortnights respectively. Peak period of infestation synchronised with the emergence of new flush.

Peak activity continued in January, 2001 recording a population of 152.7 and 158.9 larvae / 50 twigs during the first and second fortnights respectively. Activity of the pest decreased slowly from second fortnight of Februry onwards recording only 54.52 larvae / 50 twigs and least incidence was observed during March second fortnight with a population of 18.56 larvae.

Correlation and regression co-efficients between insect population and climatic factors viz., maximum and minimum temperatures, relative humidity and rainfall were worked out, co-efficients are given in Table 4. The correlation of butterfly population with maximum temperature (r = -0.8503) and minimum temperature (r = -0.8142) showed highly significant negative relationship. However, the correlation of butterfly population with relative humidity (r = 0.8323) was positive and highly significant and positive non-significant relationship was found between the larval population and rainfall (r = 0.1296).

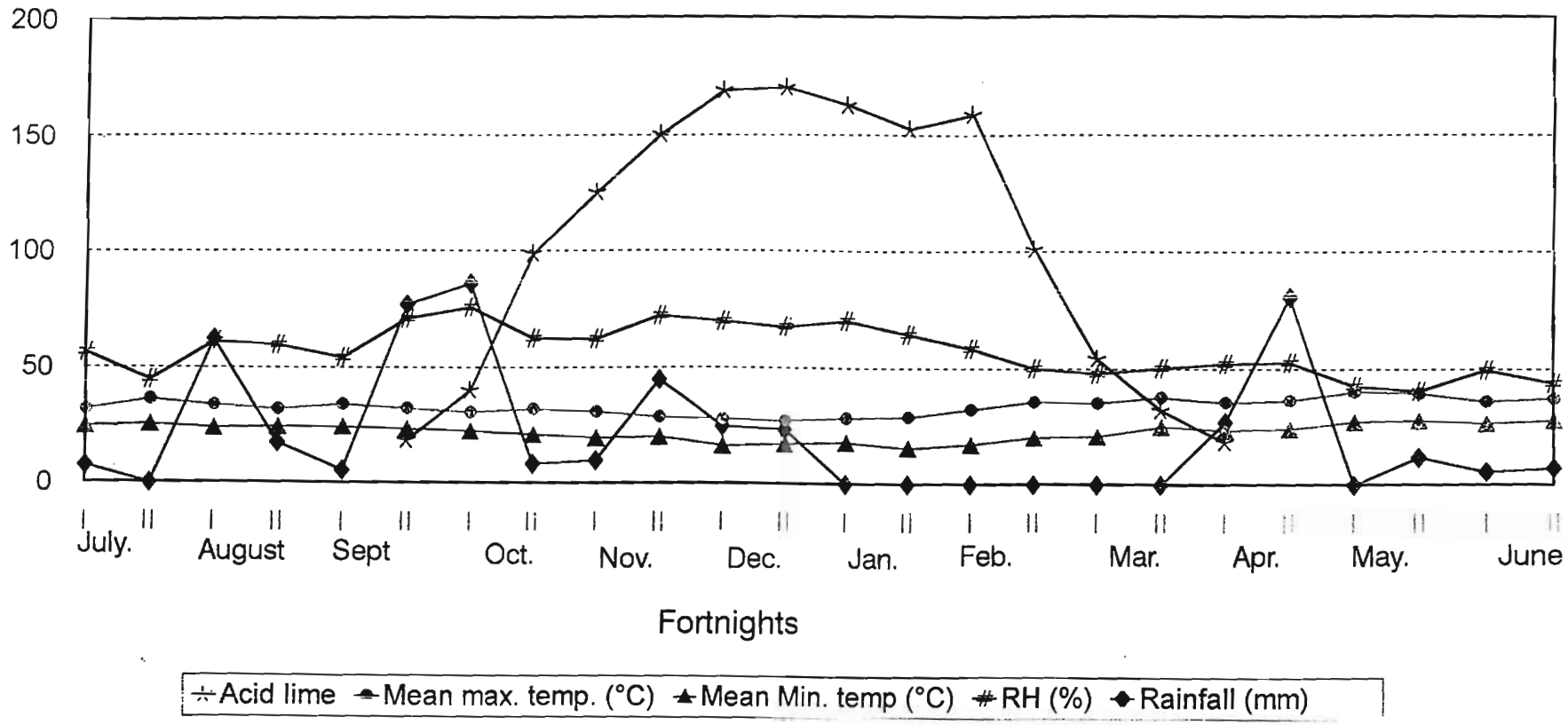
Peak activities of the citrus butterfly coincided with tender foliage. From October to first fortnight of January peak activity was recorded on sweet orange and it varied from November to January on acid lime i.e. from November to December on both the hosts insect activity was at its peak. Eventhough there was new foliage during second fortnight of January, the pest activity was low on sweet orange compared to acid lime under similar climatic conditions. It was also seen that inspite of new foliage during April and May months, no butterfly infestation was noticed on both the hosts, because of maximum temperatures prevailed during these months i.e. 36.7 and 40.5°C respectively. This indicated that presence of tender foliage may be of secondary importance where as weather factors play major role in the incidence of citrus butterfly.

Table 4 : Relationship between *Papilio demoleus* L. larval population on acid lime and weather factors

Sl. No	Particulars	Correlation co-efficient	Partial regression co-efficient	't' values
1	Mean larval population and maximum temperature	-0.8503**	4.688	0.786^{NS}
2	Mean larval population and minimum temperature	-0.8142**	-7.331	2.312*
3	Mean larval population and relative humidity	0.8323**	6.303	2.889**
4	Mean larval population and rainfall	0.1296^{NS}	-0.654	1.750^{NS}

* Significant at 5% probability
** Significant at 1% probability
NS Non-significant

Fig 2 : Seasonal abundance of Citrus butterfly, *Papilio demoleus* Linn. on Tenali Acid lime during July, 2000 to June, 2001



4.2 COMPARATIVE BIOLOGY OF CITRUS BUTTERFLY *Papilio demoleus* Linn. ON SWEET ORANGE, ACIDLIME AND CURRY LEAF

Studies on the comparative biology and morphometrics of citrus butterfly, *P. demoleus* on three different hosts were conducted under laboratory conditions. The observations were recorded under mean maximum temperature of 28.3°C, minimum temperature of 16.9°C, relative humidity of 68.3 per cent and rainfall of 24.2 mm. Data related to different developmental stages viz., egg, larva, pupa and adult were documented schematically. The behaviour of the adult with regard to pre-mating, pre-oviposition, oviposition, post-oviposition periods and longevity were observed. Duration of the different developmental stages of *P. demoleus* on the three different hosts were presented in Tables 5, 6 and 7 and morphometric data in Tables 8, 9 and 10.

4.2.1 Egg

Fertilised adult female laid eggs singly, mostly on the undersurface of tender leaves and also on tender twigs by curling its abdomen. Freshly laid eggs were creamy yellow, smooth and spherical in outline (Plates 2 and 3). Before hatching the eggs turned to greyish colour with brown streaks all over the chorion.

Plate 2. **Eggs of *P. demoleus***

Plate 3. **Enlarged egg of *P. demoleus***

Table 5 : Duration of different stages of life cycle of *Papilio demoleus* L. on Sathgudi sweet orange

S. No.	Particulars / Stage	Duration			S.D	SEM
		Minimum	Maximum	Mean		
1.	Premating period	10.50	13.21	12.39	0.97	0.306
2.	Mating period	1.45	2.05	1.62	0.27	0.085
3.	Pre-oviposition period	1.42	1.56	1.49	0.04	0.013
4.	Oviposition period	4.32	4.78	4.59	0.15	0.046
5.	Post-oviposition period	2.30	2.59	2.51	0.08	0.025
6.	Incubation period	2.65	2.98	2.91	0.10	0.030
7.	**Larval periods**					
	a. First instar	1.85	1.98	1.95	0.05	0.015
	b. Second instar	0.95	1.00	0.98	0.01	0.004
	c. Third instar	1.38	1.49	1.44	0.04	0.011
	d. Fourth instar	1.88	1.96	1.94	0.04	0.012
	e. Fifth instar	2.49	2.58	2.54	0.03	0.010
8.	Total larval period	8.84	9.00	8.90	0.06	0.018
9.	Pre pupa	0.98	1.00	0.99	0.01	0.001
10.	Pupa	7.90	8.21	8.09	0.09	0.029
11.	**Longevity of adults (with 10% sugar solution)**					
	a. Male	3.60	4.00	3.76	0.15	0.047
	b. Female	6.50	7.00	6.76	0.17	0.055
12.	Total life cycle (egg-adult)	20.99	21.00	20.99	0.01	0.001

Premating period, mating period and post oviposition periods are in hours and rest of the durations in days
SD = Standard deviation
SEM = Standard error of mean

Table 6 : Duration of different stages of life cycle of *Papilio demoleus* L. on Tenali acid lime

S. No.	Particulars / Stage	Duration			S.D	SEM
		Minimum	Maximum	Mean		
1.	Premating period	10.55	13.36	12.39	0.97	0.306
2.	Mating period	1.46	2.06	1.62	0.97	0.306
3.	Pre-oviposition period	1.55	1.72	1.64	0.08	0.024
4.	Oviposition period	4.05	4.35	4.22	0.07	0.024
5.	Post-oviposition period	3.55	4.20	3.84	0.28	0.088
6.	Incubation period	3.12	3.45	3.41	0.09	0.030
7.	**Larval periods**					
	a. First instar	2.98	3.05	3.03	0.02	0.006
	b. Second instar	3.05	3.19	3.16	0.04	0.012
	c. Third instar	3.95	4.05	4.00	0.02	0.008
	d. Fourth instar	3.15	3.35	3.29	0.06	0.021
	e. Fifth instar	3.98	4.07	4.05	0.03	0.049
8.	Total larval period	16.65	17.05	16.96	0.15	0.009
9.	Pre pupa	1.02	1.06	1.04	0.01	0.003
10.	Pupa	8.80	9.22	9.06	0.19	0.061
11.	**Longevity of adults (with 10% sugar solution)**					
	a. Male	3.72	3.90	3.83	0.06	0.018
	b. Female	6.65	6.85	6.77	0.06	0.019
12.	Total life cycle (egg-adult)	30.75	31.30	31.16	0.16	0.049

Premating period, mating period and post oviposition periods are in hours and rest of the durations in days
SD = Standard deviation
SEM = Standard error of mean

Table 7 : Duration of different stages of life cycle of *Papilio demoleus* L. on curry leaf

S. No.	Particulars / Stage	Duration			S.D	SEM
		Minimum	Maximum	Mean		
1.	Premating period	10.55	13.55	12.39	0.97	0.306
2.	Mating period	1.46	2.05	1.62	0.27	0.085
3.	Pre-oviposition period	1.55	1.80	1.72	0.08	0.025
4.	Oviposition period	2.59	3.35	3.15	0.14	0.044
5.	Post oviposition period	19.55	20.55	20.20	0.36	0.114
6.	Incubation period	2.99	3.05	3.02	0.02	0.007
7.	**Larval periods**					
	a. First instar	6.99	7.02	7.01	0.01	0.003
	b. Second instar	1.53	1.56	1.55	0.01	0.002
	c. Third instar	1.98	2.02	2.01	0.01	0.003
	d. Fourth instar	2.51	2.55	2.53	0.01	0.003
	e. Fifth instar	3.32	3.36	3.34	0.01	0.003
8.	Total larval period	16.42	16.51	16.47	0.02	0.006
9.	Pre pupa	1.02	1.06	1.04	0.01	0.003
10.	Pupa	7.90	8.21	8.09	0.09	0.029
11.	**Longevity of adults (with 10% sugar solution)**					
	a. Male	3.62	3.85	3.72	0.08	0.025
	b. Female	6.25	6.52	6.44	0.08	0.025
12.	Total life cycle (egg-adult)	28.65	28.72	28.69	0.02	0.006

Premating period, mating period and post oviposition periods are in hours and rest of the durations in days
SD = Standard deviation
SEM = Standard error of mean

Table 8 : Morphometric data of *Papilio demoleus* L. on Sathgudi sweet orange

S. No.	Particulars / Stage	Measurements in "mm"			S.D	SEM
		Minimum	Maximum	Mean		
1.	**Egg**					
	Diameter	0.91	1.09	1.03	0.04	0.020
2.	**Newly hatched caterpillar**					
	a. Length b. Width	2.10 0.31	2.65 0.49	2.39 0.39	0.17 0.05	0.052 0.016
3.	**First instar larva**					
	a. Length b. Width c. Width of head capsule	4.51 1.50 0.50	5.60 1.80 0.80	4.95 1.65 0.65	0.30 0.09 0.10	0.094 0.028 0.031
4.	**Second instar larva**					
	a. Length b. Width c. Width of head capsule	8.90 2.50 0.80	9.31 3.00 1.10	9.09 2.81 0.98	0.14 0.19 0.11	0.043 0.062 0.033
5.	**Third instar larva**					
	a. Length b. Width c. Width of head capsule	12.01 3.45 1.41	14.50 4.00 1.70	13.61 3.78 1.58	0.82 0.19 0.09	0.258 0.062 0.028
6.	**Fourth instar larva**					
	a. Length b. Width c. Width of head capsule	22.01 5.35 2.40	29.00 6.00 2.70	25.60 5.56 2.53	1.85 0.27 0.09	0.585 0.084 0.028
7.	**Fifth instar larva**					
	a. Length b. Width c. Width of head capsule	38.01 6.50 3.30	44.00 7.20 3.80	41.30 6.99 3.62	2.19 0.21 0.15	0.693 0.066 0.047
8.	**Pre pupa**					
	a. Length b. Width	25.00 7.50	28.01 8.00	26.70 7.89	0.90 0.14	0.280 0.045
9.	**Pupa**					
	a. Length b. Width	29.00 8.80	32.01 9.41	30.55 9.03	1.15 0.22	0.360 0.069
10.	**Adult moth**					
	1. Male					
	a. Length (head to tip of abdomen)	25.02	29.00	26.80	1.40	0.440
	b. Width c. Wing expanse	5.80 87.01	6.10 92.04	5.94 89.90	0.11 1.37	0.034 0.433
	2. Female					
	a. Length (head to tip of abdomen)	26.01	30.00	28.20	1.40	0.440
	b. Width c. Wing expanse	6.02 88.00	6.40 94.01	6.19 90.20	0.13 1.98	0.041 0.626

Mean values of 10 samples
SD = Standard deviation
SEM = Standard error of mean

Table 9 : Morphometric data of *Papilio demoleus* L. on Tenali acid lime

S. No.	Particulars / Stage	Measurements in 'mm'			S.D	SEM
		Minimum	Maximum	Mean		
1.	**Egg**					
	Diameter	0.92	1.07	1.03	0.04	0.013
2.	**Newly hatched caterpillar**					
	a. Length b. Width	2.05 0.30	2.59 0.50	2.30 0.38	0.14 0.05	0.044 0.016
3.	**First instar larva**					
	a. Length b. Width c. Width of head capsule	4.45 1.42 0.50	5.35 1.75 0.79	4.88 1.58 0.63	0.24 0.08 0.10	0.076 0.025 0.032
4.	**Second instar larva**					
	a. Length b. Width c. Width of head capsule	8.02 2.35 0.78	9.12 2.85 1.09	8.61 2.49 0.97	0.39 0.18 0.11	0.123 0.057 0.035
5.	**Third instar larva**					
	a. Length b. Width c. Width of head capsule	12.00 3.45 1.40	14.25 3.98 1.68	13.39 3.68 1.57	0.62 0.18 0.09	0.196 0.057 0.028
6.	**Fourth instar larva**					
	a. Length b. Width c. Width of head capsule	21.90 5.30 2.40	29.00 5.90 2.65	24.04 5.51 2.50	2.22 0.27 0.09	0.703 0.085 0.028
7.	**Fifth instar larva**					
	a. Length b. Width c. Width of head capsule	38.02 6.45 3.30	43.50 7.00 3.80	40.48 6.66 3.62	1.61 0.18 0.15	0.509 0.057 0.047
8.	**Pre pupa**					
	a. Length b. Width	25.00 7.50	27.90 7.90	26.42 7.64	1.14 0.13	0.361 0.041
9.	**Pupa**					
	a. Length b. Width	29.00 8.75	32.00 9.40	29.98 8.57	0.84 0.21	0.266 0.066
10.	**Adult moth**					
	1. Male					
	a. Length (head to tip of abdomen)	25.00	28.85	25.55	1.32	0.418
	b. Width c. Wing expanse	5.70 87.00	6.05 91.85	5.85 87.80	0.10 1.32	0.032 0.418
	2. Female					
	a. Length (head to tip of abdomen)	25.7	30.00	27.72	1.31	0.415
	b. Width c. Wing expanse	5.95 87.5	6.30 94.00	6.02 89.98	0.11 1.97	0.035 0.623

Mean values of 10 samples
SD = Standard deviation
SEM = Standard error of mean

Table 10 : Morphometric data of *Papilio demoleus* L. on Curry leaf

S. No.	Particulars / Stage	Measurements in 'mm'			S.D	SEM
		Minimum	Max-mum	Mean		
1.	**Egg**					
	Diameter	0.92	1.07	1.03	0.04	0.013
2.	**Newly hatched caterpillar**					
	a. Length b. Width	2.05 0.30	2.55 0.50	2.28 0.38	0.14 0.05	0.044 0.016
3.	**First instar larva**					
	a. Length b. Width c. Width of head capsule	4.40 1.35 0.50	5.30 1.60 0.75	4.84 1.45 0.60	0.33 0.09 0.10	1.104 0.028 0.032
4.	**Second instar larva**					
	a. Length b. Width c. Width of head capsule	8.00 2.30 0.75	9.05 2.75 1.05	8.45 2.43 0.95	0.35 0.13 0.11	0.110 0.041 0.035
5.	**Third instar larva**					
	a. Length b. Width c. Width of head capsule	11.8 3.40 1.40	14.15 3.95 1.65	12.97 3.49 1.45	0.76 0.18 0.09	0.241 0.057 0.028
6.	**Fourth instar larva**					
	a. Length b. Width c. Width of head capsule	21.50 5.25 2.30	28.5 5.85 2.55	24.00 5.40 2.35	2.5 0.26 0.10	0.791 0.082 0.032
7.	**Fifth instar larva**					
	a. Length b. Width c. Width of head capsule	38.02 6.40 3.2	42.50 6.85 3.60	40.10 6.46 3.52	1.67 0.16 0.15	0.528 0.051 0.047
8.	**Pre pupa**					
	a. Length b. Width	25.00 7.40	27.60 7.85	25.42 7.48	1.14 0.13	0.360 0.041
9.	**Pupa**					
	a. Length b. Width	28.00 8.65	31.00 9.45	28.98 8.46	0.86 0.16	0.272 0.051
10.	**Adult moth**					
	1. Male					
	a. Length (head to tip of abdomen)	24.5	28.00	25.15	1.28	0.405
	b. Width c. Wing expanse	5.7 85.00	6.05 92.50	5.60 87.5	0.09 1.32	0.028 0.417
	2. Female					
	a. Length (head to tip of abdomen)	25.5	29.5	26.79	1.38	0.436
	b. Width c. Wing expanse	5.95 87.5	6.20 93.0	5.98 88.90	0.15 1.99	0.047 0.629

Mean values of 10 samples
SD = Standard deviation
SEM = Standard error of mean

The eggs on an average measured 1.03 mm in diameter on all the three host plants viz., sweet orange, acid lime and curry leaf. Incubation period varied from 2.65 - 2.98 days with an average of 2.91 days on sweet orange, 3.12 - 3.45 days with an average of 3.41 days on acid lime and 2.99 - 3.05 days with an average of 3.02 days on curry leaf.

4.2.2 Larval stage

During the period of larval development, five instars were observed. The details of the instars are given below.

4.2.2.1 First instar larva

The newly hatched caterpillars were less spiny, cylindrical in shape, light brown to brownish black with dirty white marking on the dorsal side of the abdomen and resembled the bird droppings in appearance. Its thoracic region is broader than the rest of the body.

The mean body length and width of newly hatched caterpillars were 2.39 and 0.39 mm on sweet orange, 2.30 and 0.38 mm on acid lime and 2.28 and 0.38 mm on curry leaf respectively.

Mean body length, width and width of head capsule of first instar larvae were 4.95, 1.65 and 0.65 mm on sweet orange, 4.88, 1.58 and

0.63 mm on acid lime and 4.84, 1.45 and 0.60 mm respectively on curry leaf. The duration of first instar larva lasted for 1.85-1.98 days with an average of 1.95 days on sweet orange, 2.98-3.05 days with an average of 3.03 days on acid lime and 6.99-7.02 days with an average of 7.01 days on curry leaf.

4.2.2.2 Second instar larva

The second instar larvae were less spiny and dark brown in colour with a dirty white line present obliquely along lateral sides of the abdomen with a break on the dorsal side (Plate 4).

The mean body length, width and head capsule width of second instar larvae were 9.09, 2.81 and 0.98 mm on sweet orange, 8.61, 2.49 and 0.97 mm on acid lime and 8.45, 2.43 and 0.95 mm respectively on curry leaf. The duration of second instar larva ranged from 0.95-1.00 days with an average of 0.98 days on sweet orange while on acid lime the duration ranged from 3.05 - 3.19 days with an average of 3.16 days and on curry leaf its duration varied from 1.53 - 1.56 days with an average of 1.55 days.

4.2.2.3 Third instar larva

The third instar larvae resembled the second instar larvae in general appearance and colouration except in size (Plate 4). Mean body length, width and head capsule width of third instar larvae were 13.61, 3.78 and 1.58 mm

Plate 4. **Different larval instars of *P. demoleus***

on sweet orange, 13.39, 3.68 and 1.57 mm on acid lime and 12.97, 3.49 and 1.45 mm respectively on curry leaf. The duration of third instar larva varied from 1.38 - 1.49 days with an average of 1.44 days on sweet orange, 3.95 - 4.05 days with an average of 4.00 days on acid lime and 1.98 - 2.02 days with an average of 2.01 days on curry leaf.

4.2.2.4 Fourth instar larva

The fourth instar larvae were almost black in colour with a little greenish tinge on all hosts. Whitish bands could be seen on meso and meta thoracic segments laterally, anterior part of abdomen and on the last anal segments. It had two red coloured sacs or osmeteria opening in the first thoracic segment dorsally at the anterior position. When disturbed, the osmeterium was pushed out from the anterior part of the prothorax that was a bifid or forked in structure. It emitted material of foul smell and is defensive in function. The mean body length, width and head capsule width of fourth instar larvae were 25.6, 5.56 and 2.53 mm on sweet orange 24.04, 5.51 and 2.5 mm on acid lime and 24.00, 5.40 and 2.35 mm respectively on curry leaf. The duration of fourth instar larva ranged from 1.88 - 1.96 days with an average of 1.94 days on sweet orange, 3.15 - 3.35 days with an average of 3.29 days on acid lime and 2.51 - 2.55 days with an average of 2.53 days on curry leaf.

4.2.2.5 Fifth instar larva

The fifth instar larvae were entirely different from the previous four instars in all aspects. They were yellowish green or green in colour. The fifth instar larva had characteristic brownish stripes on each of the eighth and ninth sternites with two semi circular yellowish bands on the elevated portion of the body. Head is pale green in colour. Two eye like spots were present on the second thoracic segment. A horn-like structure (Plate 4) was found on the dorsal side of the last body segment.

The mean body length, width and head capsule width of fifth instar larvae were 41.3, 6.99 and 3.62 mm on sweet orange, 40.48, 6.66 and 3.62 mm on acid lime and 40.10, 6.46 and 3.52 mm respectively on curry leaf. The duration of fifth instar larva varied from 2.49 - 2.58 days with an average of 2.54 days on sweet orange, 3.98 - 4.07 days with an average of 4.05 days on acid lime and 3.32 - 3.36 days with an average of 3.34 days on curry leaf.

4.2.2.6 Nature and symptoms of damage by larvae

The young larvae fed only on the fresh leaves and terminal shoots. Larvae initiated feeding from the leaf margin inwards reaching the mid-ribs. In the later stages, larvae fed even on mature leaves. In case of severe damage, the entire plant may be defoliated (Plate 5). The pest was found to

Plate 5. **Host plant defoliated by *P. demoleus***

be particularly devastating in the nurseries. Its damage to foliage seems to synchronise with fresh growth of citrus plants. The heavily attacked plants did not bear any fruits.

4.2.2.7 Total larval period

Total larval period ranged from 8.84 - 9.00 days with an average of 8.90 days on sweet orange, while on acid lime the duration varied from 16.65 - 17.05 days with an average of 16.96 days and 16.42 - 16.51 days with an average of 16.47 days on curry leaf.

4.2.3 Pre pupal stage

The fully fed caterpillars prepared a rough silken padding before pupation (Plate 6). The mean length and width of pre pupa were 26.7 and 7.89 mm on sweet orange, 26.42 and 7.64 mm on acid lime and 25.42 and 7.48 mm on curry leaf. The duration of pre-pupa varied from 0.98-1.00 days with an average of 0.99 days on sweet orange and 1.02-1.06 days with an average of 1.04 days on both acid lime and curry leaf.

4.2.4 Pupal stage

The pupal stage was referred as chrysalis. The chrysalis pupa was naked and attached to the support or stem by its tail and was held in position by silken girdle. The pupa was variable in colour from green, straw to brown.

Plate 6. **Pre-pupa of *P. demoleus***

Plate 7. **Chrysalis pupa**

There were numerous small black markings on the body. The pupa was initially green in colour and at the time of adult emergence it turned to brown colour. At the end of the pupal stage the wings and abdomen of the developing adult inside the pupal case were clearly seen (Plate 7).

The mean length and width of pupa were 29.98 and 8.57 mm on acid lime, 30.55 and 9.03 mm on sweet orange and 28.98 and 8.46 mm on curry leaf. The duration of pupa varied from 7.90-8.21 days with an average of 8.09 days on both sweet orange and curry leaf and 8.80-9.22 days with an average of 9.06 days on acid lime.

4.2.5 Total life cycle

In the present investigation, it was found that the total life cycle of citrus butterfly, *Papilio demoleus* Linn. i.e. from egg to adult ranged from 20.99-21.00, 30.75-31.30 and 28.65-28.72 days with average periods of 20.99, 31.16 and 28.69 days on three hosts viz., sweet orange, acid lime and curry leaf respectively.

4.2.6 Adult

The fully developed butterfly inside the pupal case emerged out by splitting the case dorsally. Newly emerged adult butterflies were found to possess weak wings hence, were unable to fly for 1-3 hours. Later they

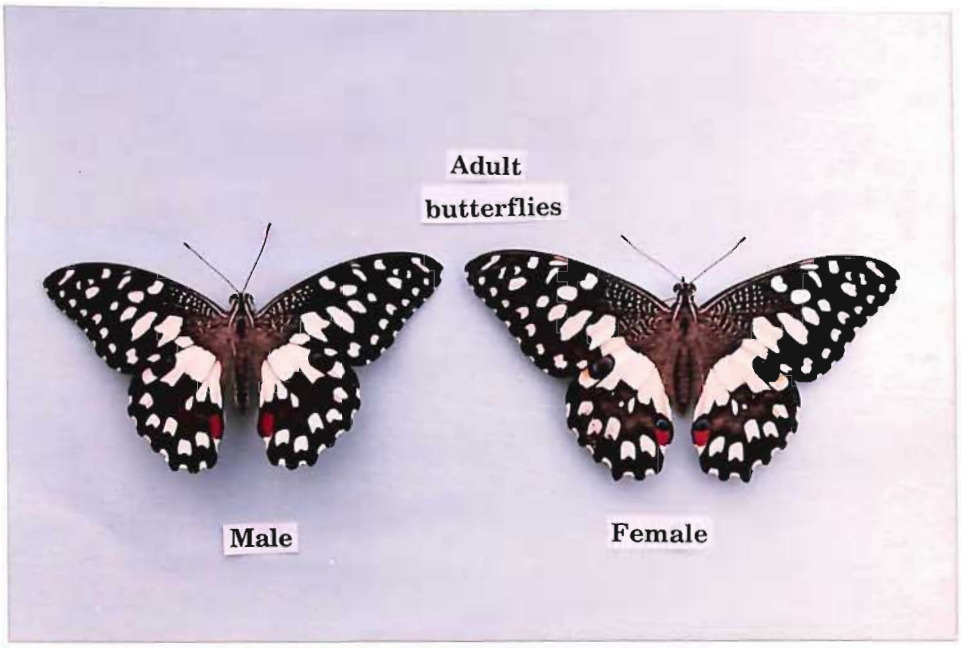


Plate 8. **Adult butterflies of *P. demoleus***

Plate 9. **Adult of *Papilio polytes***

started to fly. Adult butterflies were large and beautiful with wide wing spread. Its head and thorax were black with creamy yellow streaks on each side. The legs and abdomen were dusky black, having creamy yellow colouration on the underside of abdomen and the body was covered with black and yellow hairs. The wings were dull black, ornamented with yellow markings. The forewings were more or less triangular whereas the hind wings were rounded. There were two parallel rows of yellow spots along the outer margin of wings and a brick-red oval patch on the posterior angle of the hind wing. General colouration on the underside of wings was slightly pale and the markings were also larger. Antennae were black and rather broad at the ends, forming club like structure. The male and female sexes were differentiated by observing the abdomen. In females the tip of the abdomen was flat whereas in males, it was pointed (Plate 8).

The mean body length from head to tip of abdomen, width and wing expanse of male butterfly were 26.8, 5.94 and 89.90 mm on sweet orange, 25.55, 5.85 and 87.8 mm on acid lime and 25.15, 5.6 and 87.5 mm on curry leaf. The average body length, width and wing expanse of female butterfly recorded were 28.2, 6.19 and 90.2 mm on sweet orange, 27.72, 6.02 and 89.98 mm on acid lime and 26.79, 5.98 and 88.9 mm on curry leaf (Table 8, 9 and 10).

During these studies, another species of adult butterfly emerged that was identified as *Papilio polytes* Linnaeus (Plate 9). *Papilio polytes* was large and beautiful with wide wing spread. The head, thorax, abdomen and antennae were black in colour. Fore wings and hind wings were in full black colour having four white elongated markings in the hind wings and light whitish patches in the forewings. Red coloured semi circular markings were present along the margin of entire hind wing. There was no variation in the larva and pupa of *P. polytes* with that of *P. demoleus*.

4.2.6.1 Adult Longevity

The female adults lived longer than the male ones. Longevity of females varied from 6.5-7.0 days with an average of 6.76 days on sweet orange, 6.65-6.85 days with an average of 6.77 days on acid lime and 6.25-6.52 days with an average of 6.44 days on curry leaf. In male sex, the longevity ranged from 3.6-4.0 days with an average of 3.76 days on sweet orange, 3.72-3.9 days with an average of 3.83 days on acid lime and 3.62-3.85 days with an average of 3.72 days on curry leaf.

4.2.6.2 Pre-mating period

Pre-mating period includes the period from the time of adult emergence to mating. Pre-mating period of citrus butterfly ranged from 10.5-13.21 hours on sweet orange, 10.55-13.36 hours on acid lime and 10.55-13.55 hours on curry leaf with average periods of 12.39 hours on the three hosts.

4.2.6.3 Mating period

Mating took place in early hours of the day on tender twigs. Mating period lasted for about 1.62 hours.

4.2.6.4 Pre-oviposition period

Pre-oviposition period includes the period from the end of copulation to the first egg laying. Pre-oviposition period recorded for citrus butterfly ranged from 1.42-1.56, 1.55-1.72 and 1.55-1.80 days with averages of 1.49, 1.64 and 1.72 days on three hosts viz., sweet orange, acid lime and curry leaf respectively.

4.2.6.5 Oviposition period

The period includes the commencement of egg laying to the time when egg laying activity ceases. The mean oviposition periods on average lasted for 4.59, 4.22 and 3.15 days on sweet orange, acid lime and curry leaf respectively.

4.2.6.6 Post-oviposition period

This period includes from the ceasing of egg laying activity to the death of the adult. The mean post-oviposition period ranged from 2.51 hours on sweet orange, 3.84 hours on acid lime and 20.20 hours on curry leaf.

4.2.6.7 Sex - ratio and fecundity

Sex-ratio includes the number of male and female butterflies emerged from pupal case. Fecundity includes the average number of eggs laid by the single female butterfly. The male to female sex - ratio recorded on three hosts were 1 : 2.23 on sweet orange, 1 : 1.86 on acid lime and 1 : 1.80 on curry leaf respectively. The average fecundity per adult female was 115 on sweet orange, 106.4 on acid lime and 46.2 on curry leaf (Table 11).

4.3 NATURAL ENEMIES OF CITRUS BUTTERFLY

During the period of study of seasonal abundance of citrus butterfly, the occurrence of natural enemies was also observed and the following natural enemies were recorded.

4.3.1 Braconid parasite : ***Apanteles papilionis* Viereck.**

4.3.2 Braconid parasite : ***Apanteles* sp.**

Family : Braconidae

Order : Hymenoptera

A braconid parasite *Apanteles* sp. was an endoparasite of *Papilio demoleus* caterpillars. Parasitoid larvae after becoming full grown in the host body, came out of the body of caterpillar by making small punctures (Plate 10) and pupated in small silken cocoons (Plate 11). Adults emerged from the pupae after one week (Plate 12 and 13).

Table 11 : Sex-ratio and fecundity of *Papilio demoleus* L. on different hosts

S. No.	Host	Sex-ratio Male : Female	Fecundity / 5 females	Average fecundity / female
1.	Sathgudi (Sweet orange)	1:2.23	575	115.0
2.	Tenali (acid lime)	1:1.86	532	106.4
3.	Curry leaf	1:1.80	231	46.2

Plate 10. **Full grown larvae of *Apanteles* sp. coming out from the host body**

Plate 11. **Host larva with cocoons of *Apanteles* sp.**

Plate 12. Adult of *Apanteles papilionis* Viereck.

Plate 13. Adult of *Apanteles* sp.

Plate 14. **Dead host larva affected by *Apanteles* sp.**

Plate 15. **Adult of *Bracon hebetor***

4.3.3 Braconid parasite : ***Bracon hebetor***

Family : Braconidae

Order : Hymenoptera

Bracon hebetor resembled the *Apanteles* sp, but the cocoons formed after pupation were smaller and compact when compared to the *Apanteles* sp. (Plate 15).

4.3.4 Per cent parasitisation of citrus butterfly *P. demoleus* on Sathgudi sweet orange and Tenali acid lime

Studies on the per cent parasitisation of citrus butterfly on sweet orange and acid lime were carried out from July, 2000 to June, 2001 with a view to find out the conducive periods for the activity of natural enemies in relation to the weather parameters. Observations on natural enemy activity was recorded at fortnightly interval (Table 12).

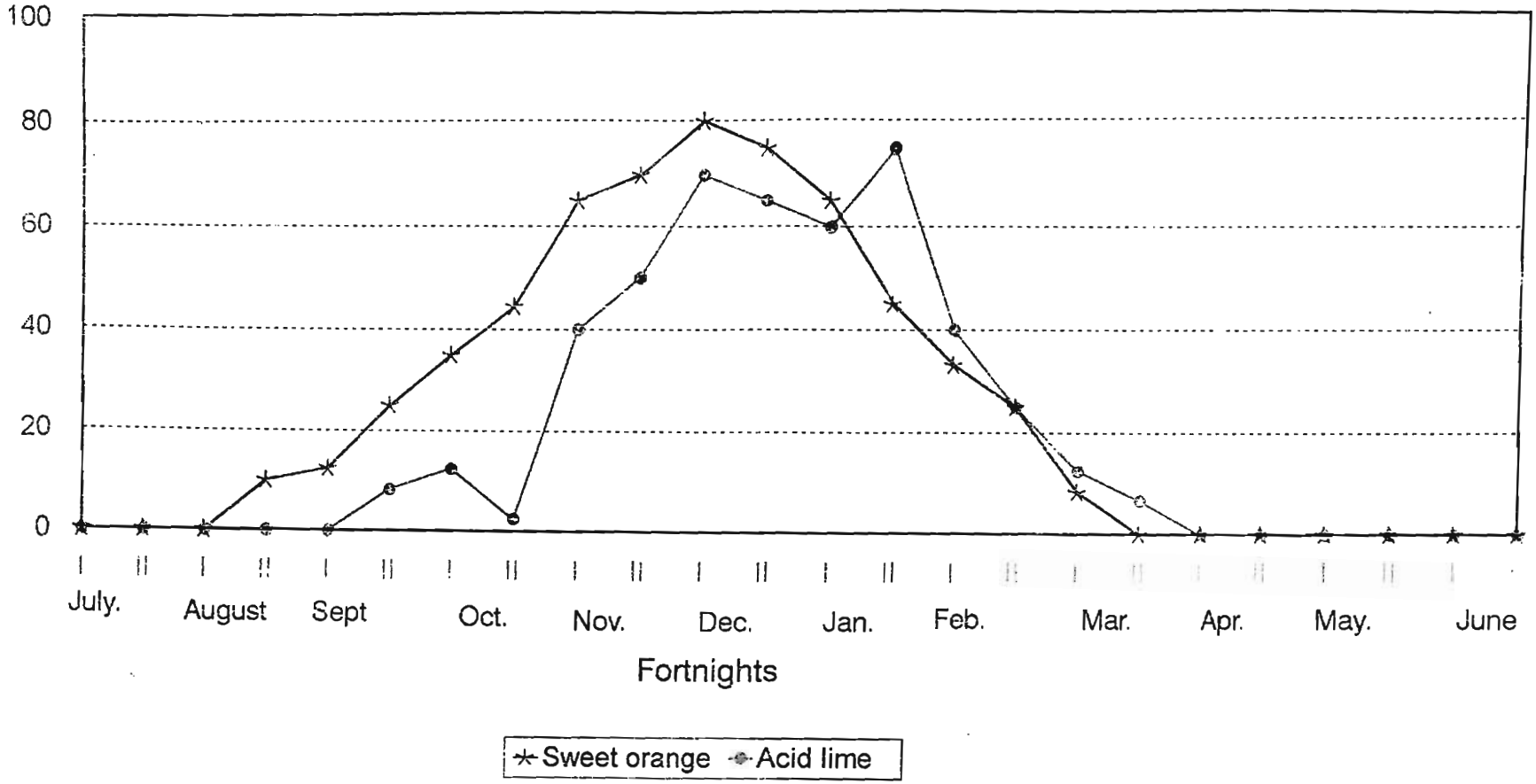
4.3.4.1 Per cent parasitisation of Braconids on Sathgudi sweet orange

There was no parasitisation of braconid parasites during July and first fortnight of August, 2000 and during March second fortnight to June, 2001. The per cent parasitisation was very less during second fortnight of August and September months. From October month onwards parasitisation increased

Table 12 : Per cent parasitisation of *Papilio* larvae on sweet orange and acid lime during July, 2000 to June, 2001.

S. No.	Period of observation	Per cent parasitisation	
		Sweet orange	Acid lime
1.	July, 2000		
	I fortnight	—	—
	II fortnight		
2.	August		
	I fortnight	—	—
	II fortnight	10.0	—
3.	September		
	I fortnight	12.5	—
	II fortnight	25.0	8.33
4.	October		
	I fortnight	35.0	12.5
	II fortnight	44.4	25.0
5.	November		
	I fortnight	65.0	40.0
	II fortnight	70.0	50.0
6.	December		
	I fortnight	80.0	70.0
	II fortnight	75.0	65.0
7.	January, 2001		
	I fortnight	65.0	60.0
	II fortnight	45.0	75.0
8.	February		
	I fortnight	33.3	40.0
	II fortnight	25.0	25.0
9.	March		
	I fortnight	8.33	12.5
	II fortnight	—	6.66
10.	April		
	I fortnight	—	—
	II fortnight	—	—
11.	May		
	I fortnight	—	—
	II fortnight	—	—
12.	June		
	I fortnight	—	—
	II fortnight	—	—

Fig 3 : Per cent parasitisation of *Papilio* larvae on Sathgudi sweet orange and Tenali acid lime



gradually recording 35.0 and 44.4 per cent in first and second fortnights. Peak activity of braconids was observed during November and December months by recording highest parasitisation of 65, 70, 80 and 75 per cent in first and second fortnights respectively. Peak activity of braconids coincided with peak activity of citrus butterfly.

Parasite activity continued in January, 2001 with 65 and 45 per cent in two fortnights. Thereafter, the braconid activity decreased, recording only 25.0 per cent parasitisation in second fortnight of February. Least activity observed during March first fortnight with 8.33 per cent.

Correlation and regression co-efficients between per cent parasitisation and climatic factors viz., maximum and minimum temperatures, relative humidity and rainfall were worked out, co-efficients are given in Table 13. The correlation between per cent parasitisation and maximum temperature ($r = -0.8072$), and minimum temperature ($r = -0.8696$) were negative and highly significant. However, the correlation with relative humidity ($r = 0.7571$) was positive and highly significant and correlation of per cent parasitisation and rainfall ($r = 0.0385$) was positive and non-significant.

Table 13 : Relationship between per cent parasitisation on sweet orange and weather factors

Sl. No	Particulars	Correlation co-efficient	Partial regression co-efficient	't' values
1	Maximum temperature and per cent parasitisation	-.8072**	.8477	$.351^{NS}$
2	Minimum temperature and per cent parasitisation	-.8696**	-4.055	-3.114**
3	Relative humidity and per cent parasitisation	.7571**	1.8046	2.140*
4	Rainfall and per cent parasitisation	$.0385^{NS}$	-.2359	-1.548^{NS}

* Significant at 5% probability
** Significant at 1% probability
NS Non-significant

4.3.4.2 Per cent parasitisation of citrus butterfly on Tenali acid lime

There was no parasitisation during July, August and first fortnight of September, 2000 and during April to June, 2001. The per cent parasitisation was very less during second fortnight of September (8.33%) and October recording 12.5 and 25 per cent in first and second fortnights. Thereafter parasitisation increased gradually recording 40 and 50 per cent in November two fortnights. Peak activity of braconids were recorded during December (70 and 65%) and January, 2001 (60 and 75%) by recording highest per cent parasitisation. Peak activity of braconids coincided with peak activity of butterfly population.

Braconid activity decreased gradually from February by recording 25 per cent during second fortnight and least activity was observed during March second fortnight with 6.66 per cent parasitisation.

Correlation and regression co-efficients between per cent parasitisation and climatic factors viz., maximum and minimum temperatures, relative humidity and rainfall were worked out, co-efficients are given in Table 14. The correlation of per cent parasitisation with maximum temperature ($r = -0.8456$) and minimum temperature ($r = -0.8827$) were negative and highly significant. However, the correlation of parasitisation with relative humidity ($r = 0.7911$) was positive and highly significant. Positive non-

Table 14 : Relationship between per cent parasitisation on acid lime and weather factors

Sl. No	Particulars	Correlation co-efficient	Partial regression co-efficient	't' values
1	Maximum temperature and per cent parasitisation	-.8456**	.4705	$.206^{NS}$
2	Minimum temperature and per cent parasitisation	-.8827**	-4.174	-3.381**
3	Relative humidity and per cent parasitisation	.7911**	1.501	1.789^{NS}
4	Rainfall and per cent parasitisation	$.0164^{NS}$	-.212	-1.470^{NS}

** Significant at 1% probability level
NS Non-significant

significant correlation was found between per cent parasitisation and rainfall (r = 0.0164).

Peak activity of braconids coincided with peak activity of the pest. From November, 2000 to January, 2001 parasitoid activity was peak on both hosts. During April and May months the activity of braconids was not recorded, as there were no host larvae. This indicates that whenever the pest activity is more, the parasite activity was also more.

4.4 INFLUENCE OF *P. demoleus* LARVAL DAMAGE ON GROWTH PARAMETERS OF SWEET ORANGE HOST PLANT

Field experiment was carried out in the Citrus Improvement Project, Tirupati during January - February, 2001 to find out the influence of damage due to *P. demoleus* on the growth of sweet orange host plant. Host plants with uniform growth were selected. Second instar larvae were released on to sweet orange plants having tender foliage at the rate of 1, 2, 3, 4 and 5 larvae per plant and a sixth plant was maintained as check without larval population for comparison and the results are presented in Table 15.

4.4.1 Observations before the release of *P. demoleus* larval population

Observations with reference to initial plant height, number of branches, number of leaves were recorded before the release of larval population.

Table 15 : Influence of *Papilio* larval feeding on growth parameters of Sathgudi host plant

Sl. No	Particulars	Mean per cent leaf damage				Mean per cent area of leaf damage				Initial plant height (cm)	Final plant height (cm)
		5 DAR	10 DAR	13 DAR	Mean	5 DAR	10 DAR	13 DAR	Mean		
1.	Host plant subjected to one larva	5.05 (6.347)	18.4 (20.402)	29.2 (31.705)	17.55 (19.49)	16.66 (23.452)	39.17 (38.59)	41.67 (40.08)	32.5 (34.05)	95	99.8
2.	Host plant subjected to two larvae	14.71 (18.167)	38.3 (38.043)	58.98 (50.567)	37.33 (35.59)	27.83 (31.622)	44.17 (41.49)	59.5 (49.35)	43.83 (40.82)	95	99.2
3.	Host plant subjected to three larvae	15.44 (18.948)	38.65 (38.252)	53.06 (46.937)	35.72 (34.71)	43.33 (41.102)	62.5 (52.36)	71.33 (55.82)	59.05 (49.76)	95	98.6
4.	Host plant subjected to four larvae	22.55 (29.658)	57.06 (49.365)	70.19 (59.652)	49.93 (46.23)	52.5 (46.44)	72.5 (58.65)	80.0 (63.68)	68.33 (56.26)	95	98
5.	Host plant subjected to five larvae	23.30 (28.03)	53.69 (47.285)	76.54 (63.402)	51.18 (46.24)	60.5 (51.068)	88.33 (71.82)	92.34 (75.43)	80.39 (66.11)	95	97.3
6.	Host plant without larval population	—	—	—		—	—			95	102
	CD at 5%	8.56	9.54	8.9	7.63	5.0	6.25	6.59	—		

DAR - Days after release
Figures in parenthesis are angular transformed values

4.4.2 Per cent leaf and per cent area of leaf damage

Observations were recorded on the number of total leaves, damaged leaves and damaged leaf area on 5th, 10th day and final observation was documented after noticing cessation of feeding activity of the larvae. Leaf area damage was assessed by visual estimation and percentages were worked out. Results are presented in Table 15.

4.4.2.1 Observations on fifth day after release of larval population

Observations taken on fifth day after release of larval population showed leaf damage in plants subjected to varied levels of larval population compared to the check plant, that was maintained free from infestation. Plants subjected to four larvae (22.55%) and five larvae (23.3%) caused significantly more damage compared to other treatments. Among the rest, damage was comparatively less in plants subjected to three larval feeding, resulting in 15.44 per cent leaf infestation followed by two larvae per plant (14.71%) and these two treatments were on par with one another. Among all the treatments, host plant subjected to one larva caused the lowest leaf damage (5.05%).

The treatments in relation to the damage severity at five days after release of larval population are arranged in the following order.

$T_4 > T_5 > T_3 > T_2 > T_1$

However, in terms of per cent leaf area damage, the treatment with five larvae showed significantly greater damage consuming 60.5 per cent of leaf area and was on par with the treatment consisting of four larval population (52.5%). Among the rest of the treatments, leaf area damage was more in treatment subjected to three larvae (43.33%) followed by two and one larva per plant recording 27.83 and 16.66 per cent of leaf area damage.

The treatments in relation to their feeding rate lie in the following order.

$T_5 > T_4 > T_3 > T_2 > T_1$

4.4.2.2 Observations on tenth day after release of larval population

All the treatments wherein the plants with different levels of population significantly showed leaf damage compared to healthy plant even after ten days of release of larval population. Plants with four larval population recorded highest per cent leaf damage (57.06%) followed by five larvae (53.69%) and were on par with one another. Among the rest, per cent infestation was high in host plant with three larval population (38.65%) that was on par with damage caused by two larvae (38.3%). There were no

$T_4 > T_5 > T_3 > T_2 > T_1$

However, in terms of per cent leaf area damage, the treatment with five larvae showed significantly greater damage consuming 60.5 per cent of leaf area and was on par with the treatment consisting of four larval population (52.5%). Among the rest of the treatments, leaf area damage was more in treatment subjected to three larvae (43.33%) followed by two and one larva per plant recording 27.83 and 16.66 per cent of leaf area damage.

The treatments in relation to their feeding rate lie in the following order.

$T_5 > T_4 > T_3 > T_2 > T_1$

4.4.2.2 Observations on tenth day after release of larval population

All the treatments wherein the plants with different levels of population significantly showed leaf damage compared to healthy plant even after ten days of release of larval population. Plants with four larval population recorded highest per cent leaf damage (57.06%) followed by five larvae (53.69%) and were on par with one another. Among the rest, per cent infestation was high in host plant with three larval population (38.65%) that was on par with damage caused by two larvae (38.3%). There were no

significant differences among five, three and two larval treatments and were on par with each other. Least damage was noticed in the plants subjected to the feeding of one larva per plant (18.4%) showing similarity to the observations of fifth day after release of the larval population.

The treatments in relation to per cent leaf infestation at ten days after release of larval population are in the following order.

$$T_4 > T_5 > T_3 > T_2 > T_1$$

However, in case of leaf area, the treatment with five larval population showed greater damage consuming maximum leaf area of 88.33 per cent. Among the rest, plants having four and three larvae resulted in 72.5 and 62.5 per cent of damaged leaf area respectively. Plants subjected to two larvae recorded 44.17 per cent area of leaf damage and was on par with damage caused by single larva (39.17%).

Damage severity can be represented in the following order.

$$T_5 > T_4 > T_3 > T_2 > T_1$$

4.4.2.3 Observations on thirteenth day after release of larval population

In synchrony with the entry of larvae to pupation, observations were taken on the thirteenth day instead of fifteenth day. In all the treatments, the per cent leaf infestation increased compared to ten days after release of larval population and in comparison to healthy plant. Five larvae per plant caused highest per cent leaf infestation (76.54%) followed by four larvae (70.19%) and were on par with one another. Among the rest of the treatments, host plant subjected to two larvae recorded 58.98 per cent leaf damage followed by three larvae (53.06%) revealing no significant difference between these treatments. Least per cent leaf damage was recorded by single larva (29.2%) showing similarity as in the previous observations.

The treatments in respect of damage are in the following order.

$$\underline{\underline{T_5 > T_4 > T_2 > T_3 > T_1}}$$

However, the treatment with five larvae per plant showed highest damaged leaf area (92.34%) followed by four larvae consuming 80.0 per cent of leaf area. The treatments three and two larvae per plant were on par with one another loosing 71.33 and 59.5 per cent leaf area. Similar to previous observations, host plant with one larva was lowest in loosing an area of 41.67 per cent of the leaf.

The treatments are in the following order in relation to the leaf area damage.

$$T_5 > T_4 > T_3 > T_2 > T_1$$

4.4.2.4 Overall observations on per cent leaf and per cent leaf area damage due to *P. demoleus*

Host plants subjected to five (51.18%) and four larvae (49.93%) caused significantly more damage compared to other treatments. Among other treatments, infestation was comparatively less in plants subjected to two larval feeding recording 37.33 per cent leaf damage followed by three larvae per plant (35.72%) and these treatments were on par with one another. Among all the treatments, host plant having single larva caused least percentage of leaf damage (17.55%).

The overall per cent leaf damage in different treatments are arranged in the following order.

$$T_5 > T_4 > T_2 > T_3 > T_1$$

However, in terms of per cent leaf area damage, the treatment with five larval feeding showed significantly more damage loosing 80.39 per cent of leaf area followed by four (68.33%) and three (59.05%) larval population. Damaged leaf area was comparatively less in two and one larval feeding with

43.83 and 32.5 per cent. There was significant difference among all the treatments.

Observations revealed that one larva per plant caused 5.05 per cent infestation consuming 16.66 per cent leaf area on 5th day after release of larval population. By 10th day, infestation increased to 18.4 per cent with 39.17 per cent of leaf area damaged. At the end of its larval development i.e. on thirteenth day, it caused 29.2 per cent leaf infestation with 41.67 per cent damaged leaf area.

Leaf damage recorded by two larvae was 14.71 per cent with 27.83 per cent damaged leaf area on 5th day followed by 38.3 and 44.17 per cent leaf damage and damaged leaf area respectively on 10th day. Before the end of larval development i.e. on thirteenth day, the leaf damage reached to an extent of 59.98 per cent with 59.5 per cent area of the leaf.

Plant subjected to the attack of three larvae consumed 43.33 (5th day), 62.5 (10th day) and 71.33 per cent leaf area in the final observation.

Plants subjected to four and five larvae per plant caused extensive damage to the plants. Plants released with four larvae consumed 52.5, 72.5 and 80.0 per cent leaf area on 5th, 10th and final observation. Plants released

Plate 16. Host plant subjected to one larval feeding

Plate 17. Host plant infested by two larvae

Plate 18. Sweet orange plant damaged by three larvae

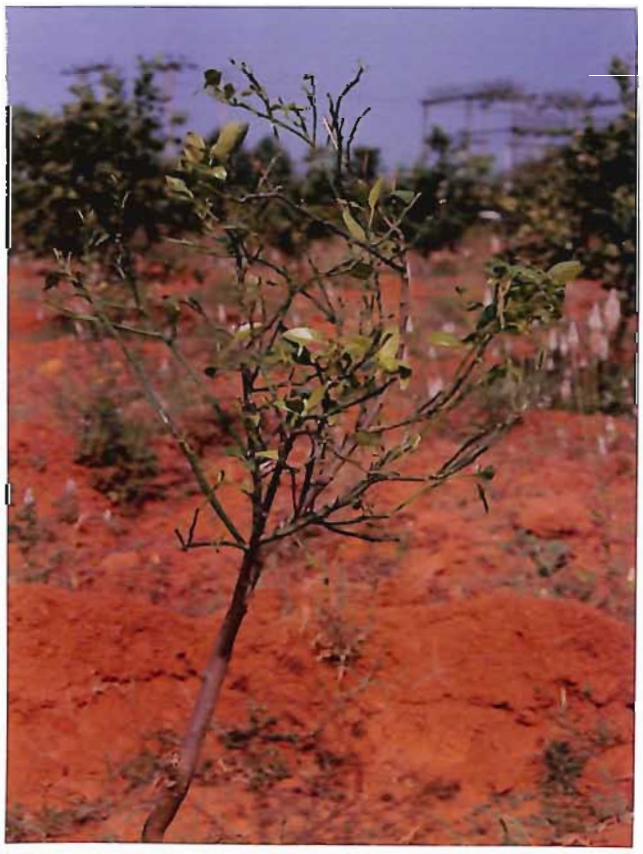


Plate 19. Host plant subjected to four larval feeding

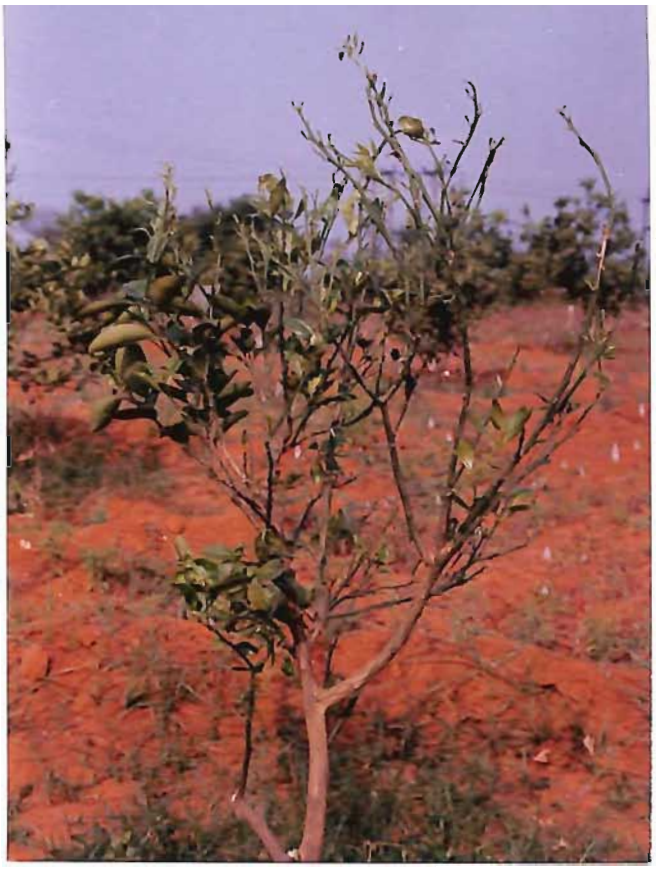


Plate 20. **Sweet orange plant heavily infested with five larval population**

Plate 21. **Sweet orange plant free from larval infestation**

with five larvae consumed approximately 60.5 per cent leaf area on 5th day itself and the rate of consumption increased gradually to 88.33 per cent (10th day). The full grown larva consumed to the maximum extent of 92.34 per cent of leaf area on 13th day after release of larval population.

From the above observations it was noticed that proportion of leaf damage increased with increase in the number of larval population.

4.4.3 Initial plant height

As the host plants were selected with uniform height, there was no deviation in the initial plant height. All plants recorded uniform height of 95 cm before the release of larval population.

4.4.5 Final plant height

Observations on the plant height were recorded at the end of the experiment i.e, 20th day after release of larval population. Host plant free from larval population was comparatively superior to all other treatments and recorded highest plant height (102 cm). Among the rest, host plant with one larva and two larvae recorded the plant heights of 99.8 cm and 99.2 cm respectively. The final plant height in case of host plant subjected to three and four larvae was 98.6 cm and 98 cm respectively. The lowest plant height (97.3 cm) was recorded in the host plant subjected to five larval population

and was inferior to the rest of the treatments, with reference to growth and development.

4.5 EVALUATION OF THE EFFICACY OF CERTAIN BIO-PESTICIDES AGAINST CITRUS BUTTERFLY, *Papilio demoleus* Linn.

4.5.1 Field experiment

A field experiment was conducted in the Citrus Improvement Project, Tirupati during second fortnight of December, 2000, to find out the efficacy of certain bio-pesticides viz., *Bacillus thuringiensis* var *Kurstaki* tested in three different concentrations viz., 0.0025, 0.005 and 0.0075 per cent, *Beauveria bassiana* (1 g / lit), neem oil 0.5 per cent, neem seed kernel extract 5 per cent and azadirachtin 0.005 per cent. These treatments were imposed after noticing the initial larval population and the effects were documented. Per cent reduction of larval population was calculated over untreated check and results are presented in Table 16.

4.5.1.1 Population of *P. demoleus* one day before spraying

Pre-treatment count on larval population was recorded one day before imposing insecticidal treatments. Pre count population was statistically non-significant indicating uniform distribution of the pest in all the treatments.

4.5.1.2 One day after spraying

Observations recorded on the larval population at one day after insecticidal application showed that all the insecticidal treatments were significantly superior to untreated check. The maximum reduction of population was obtained in *Bacillus thuringiensis* 0.005 per cent (57.46%) that was on par with B.t 0.0075 per cent (55.53%) and these treatments were found superior to lowest concentration of B.t i.e, 0.0025 per cent (37.1%). Among the rest of the treatments, *Beauveria bassiana* 1 g / lit offered 19.46 per cent larval reduction and it was on par with neem seed kernel extract at 5 per cent (19.5%), azadirachtin at 0.005 per cent (16.75%) and neem oil at 0.5 per cent (15.8%).

The efficacy of the insecticidal treatments against *P. demoleus* was found to be in the following order.

$$T_2 > T_3 > T_1 > \overline{T_4 > T_5 > T_7 > T_6}$$

4.5.1.3 Three days after spraying

Observations recorded on the larval population at three days after insecticidal spraying showed that all the insecticidal treatments were significantly superior to untreated check and the efficacy increased compared to one day after spraying. The maximum population reduction was obtained in the treatment *Bacillus thuringiensis* 0.0075 per cent (94.10%) and it was

on par with B.t at 0.005 per cent (90.77%). The insecticidal treatment B.t at 0.005 per cent concentration with population reduction of 90.77 per cent was on par with the lowest dosage of B.t i.e, 0.0025 per cent (81.41%). All the three concentrations of B.t were found significantly superior to *Beauveria bassiana* and neem products. The rest of the treatments were on par with one another by recording population reduction of 44.0 per cent in NSKE 5 per cent, 43.23 per cent in azadirachtin 0.005 per cent, 39.76 per cent in *B. bassiana* 1 g/lit and 39.0 per cent in neem oil at 0.5 per cent concentration.

The efficacy of insecticidal treatments at three days after spraying was found to be in the following order .

$$T_3 > T_2 > T_1 > T_5 > T_7 > T_4 > T_6$$

4.5.1.4 Five days after spraying

All the insecticidal treatments were significantly superior to untreated check at five days after insecticidal application. *Bacillus thuringiensis* showed increased efficacy at all the three different concentrations viz., 0.0025, 0.005 and 0.0075 per cent offering highest per cent reduction (100%) over untreated check exhibiting their consistent effect in reducing the larval population. Among the rest of the treatments neem oil (86.11%) was found to be the next superior treatment. However it was on par with neem seed kernel extract

(82.01%). Similarly, the treatments *Beauveria* and azadirachtin were on par with one another by recording population reduction of 70.77 and 74.33 per cent respectively.

The efficacy of insecticides at five days after spraying was found to be in the order of.

$$T_1 = T_2 = T_3 > T_6 > T_5 > T_4 > T_7$$

4.5.1.5 Seven days after spraying

Observations recorded on the larval population at seven days after insecticidal application showed that all the insecticidal treatments were significantly superior to untreated check. *Bacillus thuringiensis* tested in three different concentrations showed similar effect as in five days after spraying by recording 100 per cent reduction in population. In the rest of the treatments, increase in efficacy was found as against five days after spraying i.e. azadirachtin (94.93%), neem oil (93.43%), NSKE (92.68%) and *Beauveria* (91.61%). All the three neem products and *Beauveria* were on par with one another.

The efficacy of insecticides at seven days after spraying against citrus butterfly was found to be in the following order.

$T_1 = T_2 = T_3 > T_7 > T_6 > T_5 > T_4$

4.5.1.6 Ten days after spraying

All the insecticides were significantly superior to untreated check at ten days after spraying.

The three concentrations of *Bacillus thuringiensis* proved their significant superiority over other treatments. Next to B.t treatments, neem seed kernel extract and neem oil were significantly superior to azadirachtin and *B. bassiana* by recording 90.59 and 89.68 per cent reduction respectively and were on par with one another. These were followed by azadirachtin and *B. bassiana* with 84.81 and 85.19 per cent reduction over untreated check. There was no significant difference between these two treatments and were on par with each other.

The efficacy of insecticides at ten days after spraying was found to be in the following order.

$T_1 = T_2 = T_3 > T_5 > T_6 > T_7 > T_4$

4.5.1.7 Overall efficacy of the bio-pesticides against citrus butterfly

The overall efficacy of the insecticidal treatments in the control of citrus butterfly is presented in Table 14.

Bacillus thuringiensis tested in three different concentrations viz., 0.0025, 0.005, and 0.0075 per cent recorded high population reduction of 83.7, 89.65 and 89.93 per cent respectively. However these treatments were on par with one another. These treatments were found significantly superior to the remaining treatments viz., neem seed kernel extract (65.76%), neem oil (64.8%), azadirachtin (62.8%) and *B. bassiana* (61.36%). There was no significant difference among these four treatments and were on par with each other.

The overall efficacy of the insecticidal treatments against citrus butterfly was in the following order.

$$T_3 > T_2 > T_1 > \overline{T_5 > T_6 > T_7 > T_4}$$

4.5.2 Laboratory evaluation of selective formulations against *P. demoleus*

Laboratory experiment was conducted in the insectary of the Entomology Department, S.V.Agricultural College, Tirupati during second fortnight of January, 2001 with uniform sized third instar larvae to find out the efficacy of certain bio-pesticides viz., *Bacillus thuringiensis* var *Kurstaki*

Table 16 : Evaluation of certain bio-pesticides against *Papilio* larvae on sweet orange nursery

Sl. No	Treatment	Concent-ration (%)	Precount population	Per cent population reduction over control (in days)*					Mean
				1 DAS	3 DAS	5 DAS	7 DAS	10 DAS	
1	*Bacillus thuringiensis*	0.0025 (2.09×10^7)	15.3	37.1 (37.48)	81.41 (65.05)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	83.7 (73.42)
2	*Bacillus thuringiensis*	0.005 (4.23×10^7)	12.3	57.46 (49.30)	90.77 (75.17)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	89.65 (77.81)
3	*Bacillus thuringiensis*	0.0075 (6.19×10^7)	15.3	55.53 (48.23)	94.10 (77.88)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	89.93 (78.14)
4	*Beauveria bassiana*	1 g/lit (5.05×10^7)	14.7	19.46 (26.08)	39.76 (39.02)	70.77 (60.70)	91.61 (73.44)	85.19 (63.31)	61.36 (52.51)
5	Neem seed kernel extract	5	15.0	19.50 (25.42)	44.00 (41.52)	82.01 (64.95)	92.68 (76.58)	90.59 (72.17)	65.76 (56.13)
6	Neem oil	0.5	15.6	15.8 (23.05)	39.00 (38.59)	86.11 (68.20)	93.43 (77.32)	89.68 (71.36)	64.8 (55.7)
7.	*Azadirachtin* (Neemazal)	0.005	14.7	16.75 (23.66)	43.23 (41.10)	74.33 (59.57)	94.93 (78.75)	84.81 (66.37)	62.8 (53.89)
	Control		14.9	—	—	—	—	—	—
	CD at 5%			10.03	12.26	4.24	9.02	3.83	4.9

* Average of 3 replications

DAT Days after spraying

Figures in the parenthesis are angular transformed values

tested in three different concentrations viz., 0.0025, 0.005 and 0.0075 per cent, *Beauveria bassiana* (1 g/ lit) and neem oil 0.5 per cent. Per cent cumulative mortalities were worked out and the results are presented in the Table 17.

4.5.2.1 Larval mortality at one day after treatment

The treatment *Bacillus thuringiensis* tested in three different concentrations viz., 0.0025, 0.005 and 0.0075 per cent recorded highest larval mortality (53.33%) and were superior to neem oil and *Beauveria.* Next to B.t, neem oil offered 33.33 per cent mortality, however it was on par with *Beauveria bassiana* which recorded the population mortality of 23.33 per cent. All the insecticidal treatments were superior to untreated check. The efficacy of the insecticidal treatments against citrus butterfly was in the following order.

$$T_1 = T_2 = T_3 > \overline{T_5 > T_4} > T_6$$

4.5.2.2 Larval mortality at two days after treatment

Bacillus thuringiensis at all the three concentrations were found equally effective in bringing the mortality by recording 78.53, 75.2 and 72.73 per cent at the concentrations of 0.0075, 0.005 and 0.0025 per cent respectively. Next to B.t, in neem oil treatment efficacy increased recording 52.93 per cent mortality as against 33.33 per cent mortality after 24 hours observation.

Plate 22. ***P. demoleus*** **larvae infected by** ***B. thuringiensis***

mortality of 75.7 per cent. The efficacy of the insecticidal treatments at four days after treatment was found to be in the following order.

$T_1 = T_2 = T_3 > T_5 > T_4 > T_6$

4.5.2.5 Five days after treatment

Neem oil treatment showed increased efficacy (100.0%) as compared to 4th day observation (86.57%) and exhibited equal efficacy as that of three concentrations of B.t. Lowest per cent mortality was recorded in *Beauveria* (86.66%). The efficacy of insecticides at five days after treatment was found to be in the following order.

$T_1 = T_2 = T_3 = T_5 > T_4 > T_6$

4.5.2.6 Larval mortality at six days after treatment

The three concentrations of B.t and neem oil showed similar effect as in five days after treatment recording 100 per cent mortality in population and were on par with one another. *B. bassiana* showed gradual increase in the efficacy recording 92.63 per cent mortality and was superior to untreated check. The efficacy of insecticides at six days after treatment was found to be in the order of

$T_1 = T_2 = T_3 = T_5 > T_4 > T_6$

4.5.2.7 Seven days after treatment

All the insecticides were significantly effective over untreated check by recording 100.0 per cent mortality. In *Beauveria* treatment the efficacy still increased reaching 100 per cent mortality on 7th day. There was no significant difference among these treatments and were on par with each other.

4.5.2.8 Over all efficacy of the insecticidal treatments against citrus butterfly in the laboratory experiment

The overall efficacy of the insecticidal treatments in the control of citrus butterfly is presented in Table 17.

Bacillus thuringiensis tested in three different concentrations viz., 0.0025, 0.005 and 0.0075 per cent, recorded uniformly high mortality of 88.46, 89.31 and 89.79 per cent larval population respectively. Next to B.t, the treatment with neem oil offered 78.02 per cent mortality. Lowest mortality of 66.5 per cent was recorded by *Beauveria bassiana.*

The overall efficacy of the insecticidal treatments against citrus butterfly was in the following order

$$T_3 > T_2 > T_1 > T_5 > T_4 > T_6$$

Table 17 : Evaluation of bio-pesticides against *Papilio* 3rd instar larvae (Laboratory Studies)

Sl. No	Treatment	Concentration (%)	Precount population	Larval mortality (%)*							
				1 DAT	2 DAT	3 DAT	4 DAT	5 DAT	6 DAT	7 DAT	Mean
1.	*Bacillus thuringiensis*	0.0025 (2.09×10^7)	10	53.33 (46.92)	72.73 (58.54)	93.33 (79.94)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	88.46 (76.88)
2.	*Bacillus thuringiensis*	0.005 ($4.23 \times 10.^7$)	10	53.33 (46.92)	75.2 (60.21)	96.66 (82.65)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	89.31 (77.51)
3.	*Bacillus thuringiensis*	0.0075 (6.19×10^7)	10	53.33 (46.92)	78.52 (62.43)	96.66 (82.65)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	89.79 (77.82)
4.	*Beauveria bassiana*	1 g / lit (5.05×10^7)	10	23.33 (28.78)	37.2 (37.71)	50.00 (45.00)	75.7 (60.49)	86.66 (68.86)	92.63 (74.33)	100.00 (90.00)	66.50 (57.62)
5.	Neem oil	0.5	10	33.33 (35.22)	52.93 (46.68)	73.33 (59.00)	86.57 (68.55)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	78.02 (67.72)
6.	Control		10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	CD at 5%			6.91	4.12	7.82	4.05	3.49	2.98	—	3.28

* Average of 3 replications
DAT Days after treatment
Figures in the parenthesis are angular transformed values

Chapter - V

Discussion

CHAPTER - V

DISCUSSION

A thorough knowledge of the seasonal activity and the ecological factors conducive for the build up of the pest helps to evolve suitable strategies for the effective management of the pest. The results documented through various studies on these ecological aspects are discussed hereunder in the light of similar studies made else where.

5.1 SEASONAL ABUNDANCE OF CITRUS BUTTERFLY, *P. demoleus* ON SATHGUDI SWEET ORANGE AND TENALI ACID LIME

The incidence of citrus butterfly, *P. demoleus* on two prominent hosts viz., sweet orange and acid lime was found negligible during July and August, 2000 and from April to June, 2001. Pest incidence was found starting from second fortnight of August on sweet orange and during first fortnight of September on acid lime, that coincided with the emergence of new foliage.

From the second fortnight of September, the population on sweet orange increased gradually and attained peak level during October, November and December, recording highest number of 162.5, 160.4, 175.3, 180.7, 185.7 and 175.2 larvae / 50 twigs. Pest activity continued in January first fortnight (140.2) also and thereafter the population dwindled upto first fortnight of March.

On acid lime larval population increased gradually from first fortnight of October with peak activity during November-January recording highest number of 150.5, 168.9, 170.2, 162.6, 152.7 and 158.9 larvae / 50 twigs. Population was found declining subsequently in February and March months.

There was significant negative correlation between the population of *P. demoleus* and maximum and minimum temperatures and positive correlation with relative humidity and rainfall on both sweet orange and acid lime.

According to the studies of Hayes (1957), there was fresh egg laying in July and the increase of *P. demoleus* population was found in August. Ganguli and Ghosh (1967) noticed the butterfly incidence in the months of February, April, June, August and November and Maheswarababu (1988) during June and July. Results of all these studies are more or less similar to the present findings with slight variations.

Peak activity was found during September by Hayes (1957), during April and July - October according to Bindra (1969) and Nair (1975), during January and February according to Ramasubba Reddy (1984) and during August and September according to Maheswarababu (1988). These are more or less in support of the present findings. However, according to Yadav and

Rizvis (1995) peak activity was recorded during February - June at Faizabad, Uttar Pradesh. The difference in the occurrence and peak activity of the pest was due to the major variations in the weather factors from one region to another region where wide variation exists in the climatic conditions especially with reference to the temperature and humidity factors.

Pest infestation was negligible during July and August, 2000 and during hot summer months i.e. April to June of 2001. Similar observations were made by Ramasubba Reddy (1984). However, according to Hayes (1957) and Resham *et al.*, (1986) the population was negligible in winter months. According to Maheswarababu (1988), pest population declined during October and there was no population from second fortnight of November to the end of December, which were in contrary with the present investigation which might be due to variation in the climatic conditions from year to year.

It was also seen that inspite of new foliage during April and May months, no butterfly infestation was noticed on both the hosts because of maximum temperatures prevailed during these months i.e. 36.7 and 40.5°C respectively. This indicated that presence of tender foliage may be of secondary importance where as weather factors play major role in the incidence of citrus butterfly.

5.2 BIOLOGY AND MORPHOMETRICS OF CITRUS BUTTERFLY ON SWEET ORANGE, ACID LIME AND CURRY LEAF

In view of the importance of alternate host plants in supporting the population along with the cultivated hosts, a comparative study was carried out on two varieties of citrus viz., Sathgudi sweet orange and Tenali acid lime and on 'local' curry leaf which is an alternate host.

The life cycle of citrus butterfly, *Papilio demoleus* Linnaeus showed variation on the three different hosts. The results of the investigations are discussed in this chapter.

Freshly laid eggs were smooth, spherical, creamy yellow in colour prior to hatching and turned to greyish with brown streaks all over the chorion before hatching in all the three hosts. This description was in agreement with the reports of Atwal (1964), Ganguli and Ghosh (1967) and Maheswarababu (1988). The diameter of the egg was 1.03 mm on all the three hosts. More or less similar observations were made by Atwal (1964), Ganguli and Ghosh (1967), Resham *et al.,* (1986) and Maheswarababu (1988). The incubation period varied from 2.65-2.98 days on sweet orange, 3.12-3.45 days on acid lime and 2.99 - 3.05 days on curry leaf. Similar observations with slight variation were made by Maheswarababu (1988). He reported that the incubation period on an average lasted 2.96 days on

Sathgudi and Rangpur lime and 3.00 days on curry leaf. Asokan (1997) reported the incubation period as 3.4 days on acid lime. This was in full agreement with the present findings. In general, the present findings indicated that the eggs hatched within 2.7-3.5 days depending upon the temperature of the region. Atwal (1967), reported that the incubation period varied from 3-7 days on citrus. Misra and Pandey (1965) reported the incubation period as 3-6 days, Ganguli and Ghosh (1967) reported 3-4 days, Sharifi and Zarea (1970) reported 3.24 days, Badawi (1981) reported minimum of 3.1 days and maximum of 6.1 days , Resham *et al.*, (1986) reported 3-7 days, Singh and Gangwar (1989) reported 4.7 days and Radke and Kandalkar (1989) reported 5 days. However, according to Butani (1973) the incubation period was 3 days in summer and extended upto 8 days in winter. The differences in the incubation period existed due to variations in the weather factors of different regions with regard to place of work and also due to extremely low temperatures in winter months. The results revealed that during summer incubation period was shorter and the period gets prolonged in winter.

During the period of development, five larval instars were observed on all the hosts viz., sweet orange, acid lime and curry leaf. In contrary to this, an additional sixth larval instar was reported by Asokan (1997) on acid lime. The variation might be due to differences in temperature and relative humidity (22-30°C and RH of 72-80%) of different regions with regard to place of work.

The newly hatched caterpillars were less spiny, cylindrical in shape, light brown to brownish black resembled the bird droppings and found to feed on the egg shells immediately after hatching. The newly hatched caterpillar on an average measured 2.38 and 0.38 mm length and width on all three hosts. These findings were in agreement with the reports of Atwal (1964), Resham *et al.*, (1986), Ganguli and Ghosh (1967) and Maheswarababu (1988).

First instar larva on an average ranged between 4.84-4.95 mm in length and 1.45-1.65 mm in width on all the three hosts. In contrary to this Maheswarababu (1988) reported that the length and width of first instar larvae as 6.85 and 1.9 mm on sweet orange and 6.0 and 1.5 mm on curry leaf. This difference might be due to difference in climatic factors from year to year. The duration of first instar larva on an average lasted for 1.95 days on sweet orange, 3.03 days on acid lime and 7.01 days on curry leaf, which were in confirmity with the reports of Asokan (1997) and Maheswarababu (1988).However, according to Ganguli and Ghosh (1967) the duration was 2-3 days on *Citrus reticulata*. According to Singh and Gangwar (1989) the period extended upto 5.3 days on khasi mandarins. This variation is due to difference in host plants and also due to temperature variations.

The length and width of second instar larva ranged between 8.5-9.09 and 2.4-2.81 mm on three hosts. Third instar larva on an average ranged between 12.97-13.61 mm in length and 3.49-3.78 mm in width on all hosts. The length and width of fourth instar larvae were 25.6 and 5.56 mm respectively on sweet orange, 24.04 and 5.51 mm on acid lime and 24.0 and 5.4 mm respectively on curry leaf. These results were differing with the observations made by Ganguli and Ghosh (1967) recording 7.0 and 2.0 mm, 10.0 and 3.0 mm and 14.0 and 4.0 mm length and width of second, third and fourth instars respectively on *Citrus reticulata* and Maheswarababu (1988) recording length and width of 10.5 and 3.0 mm on sweet orange and 9.2 and 2.5 mm on curry leaf (second instar), 13.0 and 3.4 mm on sweet orange and 14.5 and 4.0 mm on curry leaf (third instar) and 29.5 and 6.0 mm on sweet orange and 27.3 and 5.35 mm on curry leaf (fourth instar). The deviation might be due to differences in climatic factors and also due to seasonal variations from year to year.

The duration of second, third and fourth instar larvae on an average lasted for 0.98, 1.44 and 1.94 days on sweet orange, 3.16, 4.00 and 3.29 days on acid lime and 1.55, 2.01 and 2.53 days on curry leaf respectively. Similar observations were made by Maheswarababu (1988) on sweet orange and curry leaf and Asokan (1997) on acid lime. However, Ganguli and Ghosh (1967) recorded 2-3, 2-4 and 3-4 days for second, third and fourth instar larvae

respectively on *Citrus reticulata*. Singh and Gangwar (1989) recorded the durations of second, third and fourth instar larvae as 5.1, 4.2 and 4.2 days respectively on khasi mandarins. Atwal (1977) recorded the duration of fourth instar larva as 138.3, 19.5 and 88.8 hours at 25°C, 30°C and 35°C temperatures respectively. The variation is due to climatic factors of different regions with regard to place of work.

The mean length and width of fifth instar larvae were 41.3 and 6.99 mm on sweet orange, 40.48 and 6.66 mm on acid lime and 40.10 and 6.46 mm on curry leaf. More or less similar observations were made by Atwal (1964) and Maheswarababu (1988). However, Ganguli and Ghosh (1967) recorded the length and width of fifth instar larva as 30 and 6.0 mm. The duration of fifth instar larva on an average lasted for 2.54, 4.05 and 3.34 days on sweet orange, acid lime and curry leaf respectively. In contrary to this, Ganguli and Ghosh (1967) recorded 3-5 days and Singh and Gangwar (1989) recorded 3.5 days. However, the findings of Maheswarababu (1988) and Asokan (1997) were in accordance with the present results.

Fourth and fifth instar larvae had an osmeterial gland in the first thoracic segment and this organ is defensive in function. This description was in full agreement with the Leslie and Berenbaum (1990) and Burger (1978) reporting that the secretions produced by osmeterium contained iso-butyric acid, 2-methyl butyric acid and small quantities of methyl and ethyl esters.

Mean head capsule width of *Papilio demoleus* during the first, second, third, fourth and fifth instars were 0.65, 0.98, 1.58, 2.53 and 3.62 mm on sweet orange, 0.63, 0.97, 1.57, 2.50 and 3.62 mm on acid lime and 0.60, 0.95, 1.45, 2.35 and 3.52 mm on curry leaf respectively. More or less similar findings were made by Madansuri *et al.,* (1979) and Asokan (1997).

Total larval period ranged from 8.84-9.00 days with an average of 8.90 days on sweet orange while on acid lime the duration varied from 16.65 - 17.05 days with an average of 16.96 days. The duration was 16.42 - 16.51 days with an average of 16.47 days on curry leaf. Results given by Ganguli and Ghosh (1967) revealed that the total larval period ranged from 13-18 days on *Citrus reticulata.* According to Sharifi and Zarea (1970) larval developmental period was statistically shortest on lemon and longest on mandarin orange. Yunus and Munir (1972) reported the least larval durations on citrus cultivars viz., sour orange (12.5 days), lemon (12.8 days), shaddock (13.2 days) and sweet orange (13.4 days). Badawi (1981) reported minimum and maximum larval periods of 12.9 and 22.7 days in Saudi Arabia. Maheswarababu (1988) reported shortest duration (8.96 days) on sweet orange and longest duration on curry leaf (16.50 days). The duration ranged from 15-22 days according to Radke and Kandalkar (1988) and 18 days according to Radke and Kandalkar (1989). These observations were more or less in accordance with the present investigation that clearly indicated that sweet

orange was the preferred host. In general, the total larval period varied from 8.84-17.5 days depending upon the host. However, the larval period lasted for 15.9 days in March, 11.3 days in April and 8.5 days in May - June months but it extended upto 28.6 days in November and 28.8 days in December according to Atwal (1964), 13-26 days according to Misra and Pandey (1965), 11 days in summer and 28-30 days in winter according to Butani (1973), 10-40 days according to Resham *et al.*, (1986) and 24 days according to Asokan (1997) in acid lime. It was observed that the duration of the larval period was relatively less during the present studies compared to the findings of the above authors. The contrasting differences in the total larval period might be due to variation in the temperature (16.9 - 28.3°C) and relative humidity (68.3%) of different regions with regard to place of work.

The young larvae were found feeding voraciously on fresh leaves and terminal shoots from margin to inwards and in the later stages, they even fed on mature leaves and completely defoliated the nurseries. Similar reports were made by Atwal (1964), Butani (1973) and Resham *et al.*, (1986).

Mean length and width of pre-pupa ranged between 25.42 - 26.7 mm and 7.48 - 7.89 mm on three hosts. Duration of pre-pupa, on an average, was 0.99 days on sweet orange, 1.04 days on both acid lime and curry leaf. These observations were in confirmity with Radke and Kandalkar

(1988), Maheswarababu (1988) and Asokan (1997). However, Atwal (1964 & 1977) reported 16 hours in summer and 38 hours in winter ; 22.5, 15.25 and 14.4 hours at 25°C, 30°C and 35°C respectively and 2-3 days according to Misra and Pandey (1965). The contrasting differences might be due to variation in the climatic factors from year to year.

Pupal stage was referred as chrysalis and it showed variation in colour i.e, green or brown, majority being green in colour. Similar observations were made by Atwal (1964), Butani (1973) and Resham *et al.,* (1986). However, Ramana *et al.,* (1997) reported that *P. demoleus* pupae were brown in colour and that of *P. polytes* were green. Mean length and width of pupa ranged between 28.98-30.55 mm and 8.57-9.03 mm on all the hosts. Present findings were in confirmity with the observations of Atwal (1964) and Resham *et al.,* (1986). However Ganguli and Ghosh (1967) reported shortest pupal length i.e. 15 mm and 10 mm width, and this observation deviates from present studies. The variation might be due to difference in host plant and weather conditions. Duration of pupa on an average lasted 8.09 days on both sweet orange and curry leaf and 9.06 days on acid lime. More or less similar observations were made by Ganguli and Ghosh (1967), Radke and Kandalkar (1988) and Sharifi and Zarea (1970). However the pupal period was 8.5 days in summer, 9-11 days in spring and autumn and extended upto 143 days in winter according to Atwal (1964), 7-24 days according to Misra and Pandey (1965) and 7 days

during summer and 56-98 days during winter according to Butani (1973). Atwal (1977) recorded the duration of pupal period as 246, 204 and 176.8 hours at 25°C, 30°C and 35°C temperatures respectively. Resham *et al.*, (1986) recorded the pupal duration as 8-36 days and 19.1 days according to Singh and Gangwar (1989). It was observed that the durations were negatively correlated with temperatures and positively with relative humidity.

Total life cycle from egg to adult ranged from 20.99-21.00 days on sweet orange, 30.75-31.30 days on acid lime and 28.65-28.72 days on curry leaf respectively. These observations indicated that citrus butterfly, *P. demoleus* had preferential development and growth on sweet orange compared to acid lime and curry leaf. In the present study, the order of host preference was sweet orange, curry leaf and acid lime. Similar observations were made by Maheswarababu (1988), who found that Sathgudi was found to be the most preferred host plant followed by Rangpur lime, Jambiri and curry leaf. Tripathi *et al.*, (1998) reported that the life cycle was shorter on *Citrus limon* than on *Psoralea corylifolia*, an alternate host, which is in agreement with the present findings. The insect took 33.19 days according to Sharifi and Zarea (1970), 22-42 days in summer and more than 100 days in mid winter according to Resham *et al.*, (1986) and 30-50 days on acid lime according to Asokan (1997).

Adult butterflies were large and beautiful with wide wing spread. The length, width and wing expanse of male butterfly ranged 25.15 - 26.8 mm, 5.6 - 5.94 mm and 87.5 - 89.9 mm on all the three hosts, for female ranged between 26.79 - 28.28 mm, 5.98 - 6.19 mm and 88.9 - 90.2 mm on all the hosts. More or less similar observations were made by Atwal (1964), Maheswarababu (1988) and Resham *et al.,* (1986).

Female adults on an average lived for 6.44 - 6.76 days and males lived for 3.72-3.83 days. The variation in adult longevity was in agreement with the findings of Atwal (1964). However, Singh and Gangwar (1989) recorded the longevity of 5.1 and 5.8 days for male and female butterflies respectively and Asokan (1997) recorded the duration of 4-5 days for female, slightly differing from present studies.

Pre-mating period on an average lasted 12.39 hours on the three hosts. According to Atwal (1964) this period extended from 5 to 25 hours.

Mating took place in early hours of the day on tender twigs. Mating period lasted for 1.62 hours. Similar observations were made by Atwal (1964) and Radke and Kandalkar (1988).

Pre-oviposition period was observed to be varying from 1.42 to 1.8 days with averages of 1.49, 1.64 and 1.72 days on the three hosts, viz., sweet orange, acid lime and curry leaf respectively. According to Radke and Kandalkar (1988) pre-oviposition period was 1 day. According to Maheswarababu (1988) this period was 1.52 days on sweet orange and 1.82 days on curry leaf.

Mean oviposition periods on an average lasted for 4.59, 4.22 and 3.15 days on sweet orange, acid lime and curry leaf respectively. According to Atwal (1964), the oviposition period ranged from 2-5 days, Resham *et al.*, (1986) recorded 2-5 days and Radke and Kandalkar (1988) as 2 days.

Post-oviposition period ranged from 2.5-20.2 hours. This was in agreement with the observations of Maheswarababu (1988).

The ratio of male to female was 1:2.23 on sweet orange, 1:1.86 on acid lime and 1:1.80 on curry leaf. In females the tip of the abdomen was flat where as in males it was pointed. Similar observations were made by Maheswarababu (1988).

Adult female laid eggs singly, mostly on the undersurface of tender leaves and also on tender twigs. Similar observations were made by Atwal (1964), Butani (1973) and Resham *et al.*, (1986).

Adult female on an average laid 115 eggs on sweet orange, 106.4 eggs on acid lime and 46.2 eggs on curry leaf. Similar observations were made by Maheswarababu (1988) and Atwal (1964). However, Resham *et al.*, (1986) reported average fecundity of 75-120 eggs per female. According to Misra and Pandey (1965) fecundity ranged from 40-183 eggs. Radke and Kandalkar (1988 and 1989) recorded 15-22 eggs per female. Asokan (1997) recorded 12 eggs / day / female. These reports showed variation in respect of fecundity compared to the present studies which might be due to difference in the nutritional status of the host and weather factors mainly temperature.

5.3 NATURAL ENEMIES OF CITRUS BUTTERFLY

During the period of study three braconid parasitoids viz., *Apanteles papilionis* Viereck, *Apanteles* sp. and *Bracon hebetor* were observed as larval parasitoids of citrus butterfly. These observations were in agreement with the findings of Narayanan and Gopalakrishnan (1984), Krishnamoorthy (1987), Krishnamoorthy and Singh (1988) and Balagangadhar Tilak (1992).

Studies on the natural parasitisation of *Papilio demoleus* Linn. by the braconid larval parasitoids revealed that the parasitisation was negligible on both the hosts viz., sweet orange and acid lime in the months of July and August, 2000 and April to June, 2001, which was chiefly due to absence of larval population in nature during these months.

On sweet orange, the pest appearance was observed from August second fortnight onwards and subsequently parasitisation by braconids was also observed. The parasitisation increased with peak infestation of the pest and highest rate of parasitisation was observed during November to January months recording 65.0, 70.0, 80.0, 75.0, 65.0 and 45.0 per cent in first and second fortnights respectively. During these months, spraying of insecticides having adverse effects on natural enemies must be avoided. Further safer chemicals like neem products can be sprayed. Aqueous extract of NSKE sprayed on *Spodoptera litura* eggs before and after parasitisation did not affect the emergence of egg parasitoid, *Telenomus remus* (Abdul Kareem, 1999).

On acid lime, though the pest incidence was observed during first fortnight of September, the parasitisation was negligible in the first fortnight, recording 8.33 per cent in second fortnight. Thereafter parasitisation increased gradually, recorded highest rate of 50.0, 70.0, 65.0, 60.0 and 75.0 per cent from November second fortnight to January months respectively. The parasitisation increased with increase in rainfall and relative humidity and decreased with increase in mean maximum and minimum temperatures.

Correlation co-efficient values of -0.8072, -0.8696, 0.7571 and 0.0385 were observed between average maximum temperature, minimum temperature,

relative humidity and rainfall respectively on sweet orange and correlation co-efficient values of -0.8456, -0.8827, 0.7911 and 0.0164 on acid lime. Krishnamoorthy and Singh (1988) observed negative correlation between *A. papilionis* maximum temperature (-0.060) and positive relationship with minimum temperature (0.377), rainfall (0.370) and relative humidity (0.386). The present results were in confirmity with above findings except for minimum temperature. This may be due to variation in climatic conditions of Bangalore where Krishnamoorthy and Singh (1988) studied the parasitisation of *A. papilionis* compared to Tirupati conditions where present studies were undertaken. Balraj Singh and Anand (1982) reported that high temperature and low relative humidity affected the survival of *Apanteles flavipes* (Cam.).

5.4 INFLUENCE OF *PAPILIO* LARVAL DAMAGE ON GROWTH PARAMETERS OF SATHGUDI HOST PLANT

The studies conducted to find out the influence of *Papilio* larval damage on growth parameters of sweet orange (cv. Sathgudi) host plant revealed that all the treatments which were subjected to different levels of larval population caused significant damage compared to healthy plant. Damage severity was significantly less in first three larval treatments compared to four and five larvae. The treatments consisted of four and five larvae per plant, caused extensive damage to the plants. Plant subjected to five larvae caused significantly more damage, and consumed approximately

60.5 per cent leaf area on 5th day and there after rate of consumption increased gradually reaching 88.33 per cent on 10th day and 92.34 per cent on the day of final observation (13th day). This treatment recorded the least plant height of 97.3 cm. Host plant with four larvae recorded 52.5, 72.5 and 80 per cent damaged leaf area on 5th, 10th and 13th day observations. However, damage severity decreased for the rest of the treatments recording 71.33 per cent leaf area for three larvae, 59.5 per cent leaf area for two larval treatment at the end of their larval development. Single larval treatment caused significantly lowest damage by consuming 16.66 per cent leaf area on 5th day. By 10th day infestation increased to 39.17 per cent and at the end of larval stage, it consumed 41.67 per cent leaf area, recording final plant height of 99.8 cm. Host plant free from larval population recorded highest plant height (102 cm). Atwal (1964) reported that full grown larva consumed at the rate of two square inches per day, consuming 20 square inches in its entire life.

5.5 EVALUATION OF THE EFFICACY OF CERTAIN BIO-PESTICIDES AGAINST CITRUS BUTTERFLY, *Papilio demoleus* Linn.

In field experiment the data recorded on the butterfly population at different days after insecticidal application revealed that all the insecticidal treatments were significantly superior to untreated check in reducing the larval

population of citrus butterfly. In all the insecticidal treatments, population reduction was less initially i.e, at one day after spraying. Subsequently in all the insecticidal treatments, the percentage of larval reduction increased gradually upto 5th day after application. The bacterial insecticide, *Bacillus thuringiensis* var. *Kurstaki* tested in 3 different concentrations recorded highest per cent reduction (100%) over untreated check at five days after spraying and these treatments showed their persistent efficacy upto 10 days after application by maintaining the same trend of population reduction. But in case of the botanical insecticides viz., neem oil, neem seed kernel extract and azadirachtin; fungal insecticide, *Beauveria bassiana,* the efficacy increased slightly from 5th to 7th day after application, later their persistence action decreased at 10 days after spraying. Although low mortality was reported initially, the botanicals had strong antifeedant and repellent effects and were effective as moulting inhibitors.

In laboratory experiment, data recorded at 24 hrs interval on the larval mortality at different days after insecticidal treatment revealed that percentage of larval mortality was less initially and increased subsequently. The bacterial insecticide, *Bacillus thuringiensis* recorded highest mortality (100%) at four days after treatment. The botanical insecticide, neem oil showed its increased efficacy recording 100 per cent mortality at five days after treatment. But in case of fungal insecticide, *Beauveria bassiana*, the mortality was at a slower

ate initially (23.33%) and attained 100 per cent at seventh day after reatment.

The superiority of *Bacillus thuringiensis* in the control of citrus butterfly, *P. demoleus* in the present study was in agreement with the findings of Resham *et al.*, (1986) and Johnson *et al.*, (1995), with regard to its toxicity to early and later instar larvae against another species of citrus butterfly, *Papilio glaucus* and *P. canadensis*. The toxicity persisted upto 30 days. Shivankar (1999) reported Dipel (*B. thuringiensis* Berl.) at 0.05 per cent concentration was effective against lemon butterfly, *P. demoleus*. Venkadasubramanian and David (1999) reported, *B.thuringiensis* in combination with botanicals gave effective results against *Spodoptera litura* and *Helicoverpa armigera.*

Next effective treatments were botanicals viz., neem seed kernel extract, neem oil and azadirachtin. The effectiveness of neem products in controlling citrus butterfly was reported by Solunke and Deshpande (1991), Balagangadhar Tilak (1992), Ranjeet Singh *et al.*, (1996) and Chauke *et al.*, (1999).

Among all the treatments, the fungal insecticide *B. bassiana* was the least effective chemical against *P. demoleus* in bringing mortality. Shivankar

(1999) reported that the fungus, *Fusarium* sp. caused mortality of lemon butterfly, *P. demoleus.*

The efficacy of *Bacillus thuringiensis* (Halt, 5% WP) even at low dosages (0.0025% and 0.005%) was significantly felt in both laboratory and field studies under the situations, where larval parasitoids are active, it is wise to confine to this microbial insecticide for reduction of *P. demoleus*, a serious defoliator on young trees of sweet orange and acid lime.

Chapter - VI

Summary

CHAPTER - VI

SUMMARY

Among the various insects attacking citrus, citrus butterfly, *Papilio demoleus* Linnaeus is an important defoliating pest. Considering the harmful effects of chemical pesticides on natural enemies, and the meagre information available on bio-pesticides in the management of citrus butterfly, *P. demoleus* an attempt was made to orient the studies on seasonal abundance, comparative biology, natural parasitisation of *P. demoleus*, influence of pest on growth parameters of host plant and techniques of pest management. Studies were conducted at Citrus Improvement Project, Tirupati during July, 2000 to June, 2001.

Seasonal abundance of citrus butterfly (*P. demoleus*) was studied on Sathgudi sweet orange and Tenali acid lime cultivars. On both the hosts, citrus butterfly population was negligible during July and August, 2000 as well as from April to June, 2001. The pest reached to its peak activity during October, November and December months with continued activity in January on sweet orange and during November, December and first fortnight of January on acid lime. Thereafter, pest activity decreased slowly from February first fortnight to March second fortnight. With the increasing temperatures from March month onwards the pest incidence was negligible during summer

months. During March - June, the climatic conditions prevailed were mean maximum temperature of 35.50 - 40.55°C, minimum temperature of 2.10-28.0°C, low relative humidity of 40.75 - 53.0 per cent and rainfall of 0.00-27.6 mm.

The correlation studies with reference to the population of *P. demoleus* on both hosts viz., sweet orange and acid lime indicated that maximum and minimum temperatures had negative relationship whereas, relative humidity and rainfall had positive relationship. The present studies clearly showed that the peak periods of infestation synchronised with the emergence of new flush.

Biology of citrus butterfly was carriedout on three different hosts viz., sweet orange, acid lime and curry leaf under laboratory conditions where the mean maximum and minimum temperatures were 28.3 and 16.9°C and relative humidity was 68.3 per cent. On an average pre-mating period on sweet orange, acid lime and curry leaf was 12.39 hours. Mating occurred during day time which lasted for about 1.62 hours whereas, pre-oviposition period ranged from 1.5-1.7 days. Oviposition period lasted for 4.59, 4.22 and 3.15 days on sweet orange, acid lime and curry leaf respectively. Post-oviposition period ranged from 2.51 hours on sweet orange, 3.84 hours on acid lime and 20.2 hours on curry leaf. The male to female sex ratio recorded on three hosts were 1:2.23 on sweet orange, 1:1.86 on acid lime and 1:1.80

on curry leaf. Average fecundity was 115 on sweet orange, 106.4 on acid lime and 46.2 on curry leaf. Incubation periods were 2.9 days on sweet orange, 3.4 days on acid lime and 3.02 days on curry leaf. During the period of development, five larval instars were observed. The duration of larval period lasted for 8.90 days on sweet orange, 16.96 days on acid lime and 16.47 days on curry leaf. Pre-pupal stage lasted for 1.00 day uniformly on all the hosts. The mean duration of pupal period was 8.09 days on both sweet orange and curry leaf and 9.06 days on acid lime. Total life cycle from egg to adult was completed in 20.99 days on sweet orange, 31.16 days on acid lime and 28.69 days on curry leaf. Male and female adults lived for 3.76 and 6.76 days respectively on sweet orange, 3.83 and 6.77 days on acid lime and 3.72 and 6.44 days on curry leaf.

These observations indicated that the order of host preference of *P. demoleus* was sweet orange, curry leaf and acid lime.

During the period of study three braconid larval parasitoids viz., *Apanteles papilionis* Viereck, *Apanteles* sp and *Bracon hebetor* were recorded.

Effect of weather factors on braconid larval parasitoids of lemon butterfly, *P. demoleus* on sweet orange and acid lime (July, 2000 to June, 2001) revealed that parasitisation was observed during second fortnight

of August on sweet orange and during second fortnight of September on acid lime and increased gradually in the months of September and October attaining peak activity during November, December and January recording highest percentages of 65, 70, 80, 75, 65 and 45 per cent in first and second fortnights respectively on sweet orange and during December (70 and 65%) and January (60 and 75%) on acid lime. The parasitisation started to decline in the months of February and March and was almost nil in the months of April, May, June and July. A significant negative correlation existed between per cent parasitisation and maximum and minimum temperatures. A significant positive correlation was found between per cent parasitisation and relative humidity while a non-significant positive correlation was found between per cent parasitisation and rainfall on both sweet orange and acid lime.

Studies conducted to know the influence of damage due to *P.demoleus* on growth of host plant revealed that all the treatments where in the plants subjected with different levels of larval population showed significant leaf damage compared to the healthy plant. In the order of damaging effectiveness, one larva per plant caused significantly least damage (5.05%) consuming 16.66 per cent leaf area on 5th day and the infestation increased by 10th day recording 39.17 per cent damaged leaf area and at the end of the larval development (13th day), 41.67 per cent of the leaf area was consumed. Damaged leaf area recorded by two larvae was 27.83, 44.17 and 59.5 per

cent on 5th, 10th and 13th day respectively. Plant subjected to the infestation of three larvae consumed the leaf to an extent of 43.33 per cent (5th day), 62.5 per cent (10th day) and 71.33 per cent leaf area on final observation. The treatments four and five larvae per plant caused significantly extensive damage to the plants feeding 52.5 and 60.5 per cent (5th day), 72.5 and 80 per cent (10th day) and 88.33 and 92.3 per cent of leaf area on thirteenth day after release of larval population.

Host plant free from the infestation of *P. demoleus* was recorded highest plant height (102 cm) compared to host plants subjected to larval damage. As the damage severity increased with increase in larval population, there was no considerable increase in final plant height in the subsequent treatments recording 99.8, 99.2, 98.6 and 98 cm for one, two, three and four larvae respectively. The lowest plant height of 97.3 cm was recorded in the five larval population of *P. demoleus* per plant.

Field and laboratory experiments were conducted to evaluate the efficacy of certain bio-pesticides against citrus butterfly, *P. demoleus*. Data recorded on the larval population of citrus butterfly at different periods after insecticidal application revealed that all the insecticidal treatments were significantly superior to untreated check. The overall efficacy of field trial after insecticidal application revealed that *Bacillus thuringiensis*

formulation (5% WP) tested in three different concentrations (0.0025%, 0.005% and 0.0075%) was the most effective treatment with 83.7, 89.65 and 89.93 per cent reduction in population respectively. *B. thuringiensis* was followed by botanical insecticides viz., neem seed kernel extract, neem oil and azadirachtin with 65.76, 64.8 and 62.8 per cent reduction of pest. These were followed by *Beauveria bassiana* (1 g / lit) offering lowest control i.e. 61.36 per cent reduction over untreated check.

However, the citrus plants sprayed with neem oil, neem seed kernel extract, azadirachtin and *Beauveria bassiana* showed reinfestation after 10 days of treatmental application whereas on the B.t treated plots, there was perpetuation of its effect for a longer period.

Laboratory studies conducted against third instar larvae of *P. demoleus* with *B. thuringiensis*, *B. bassiana* and neem oil revealed that *B. thuringiensis* was the most effective treatment recording 88.46, 89.31 and 89.79 per cent mortality at 0.0025, 0.005 and 0.0075 per cent concentrations respectively. Neem oil (0.5%) ranked second with 78.02 per cent mortality. *B.bassiana* (1 g / lit) was the least effective treatment comparatively as it recorded 66.5 per cent mortality only.

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